Cornell University
Announcements

College of Engineering

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1973–74

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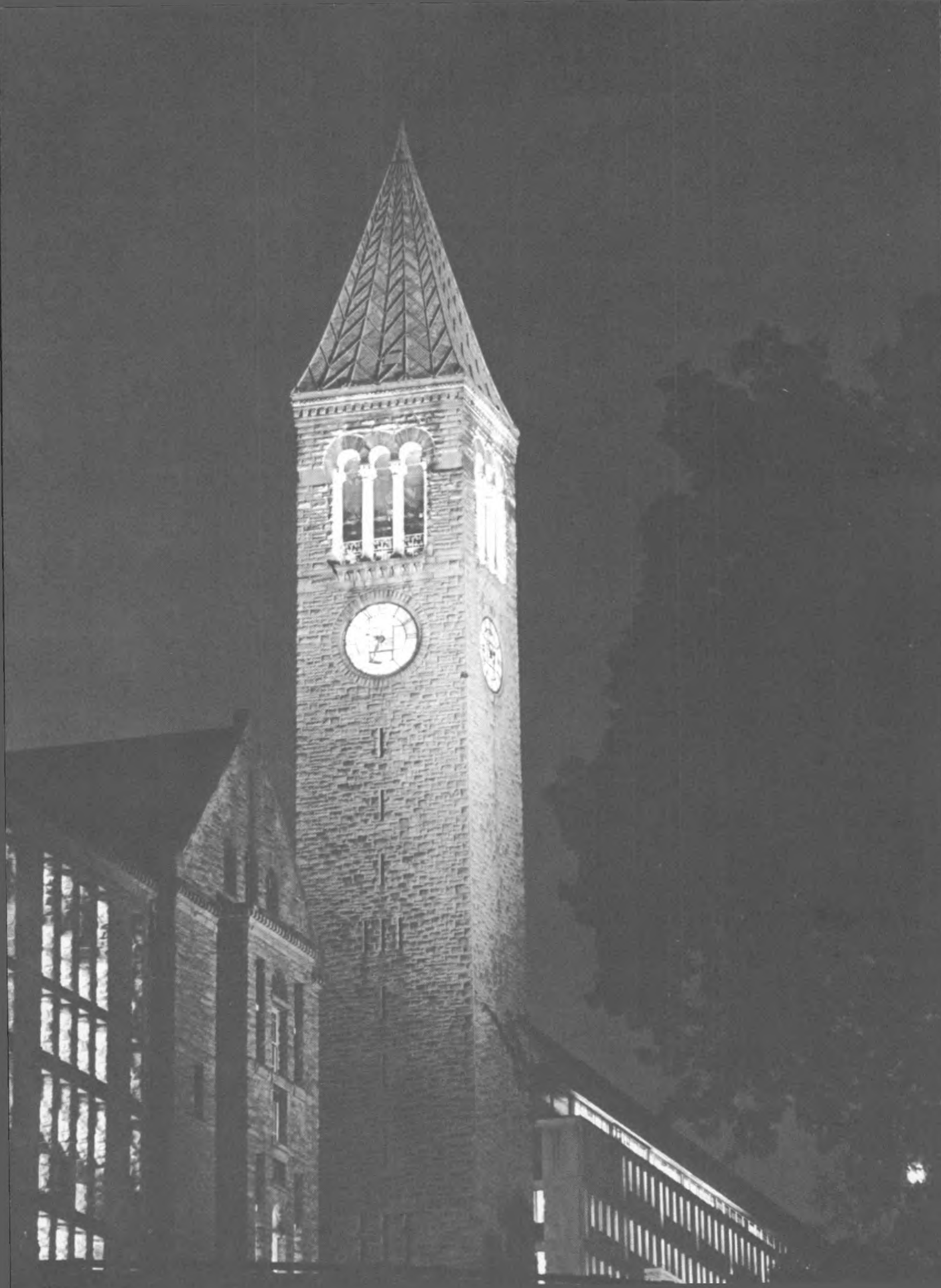


Announcements

Contents

The courses and curricula described in this *Announcement*, and the teaching personnel listed herein, are subject to change at any time by official action of Cornell University.

Further Information

Undergraduates

All prospective engineering students should write for a copy of the *Announcement of General Information,* which describes the University community in greater detail. *Engineering at Cornell,* an illustrated *Announcement,* has been prepared especially for precollege students, and it too may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York 14850.

Graduates

The *Announcement of the Graduate School* should be consulted for additional information regarding admission, financial aid, and degree requirements. Also available is an illustrated *Announcement, Graduate Study in Engineering and Applied Science,* which contains information on various research programs and areas of study. These publications may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York 14850.

1973–74

Cornell Academic Calendar

Registration, new students	Thursday, August 30
Registration, continuing and rejoining students	Friday, August 31
Fall term instruction begins	Monday, September 3
Instruction suspended for Thanksgiving recess, 1:10 p.m.	Wednesday, November 21
Instruction resumes	Monday, November 26
Fall term instruction ends, 1:10 p.m.	Saturday, December 8
First day of final examinations	Thursday, December 13
Last day of final examinations	Saturday, December 22
Registration, new and rejoining students	Thursday, January 24
Registration, continuing students	Friday, January 25
Spring term instruction begins	Monday, January 28
Instruction suspended, 1:10 p.m.	Saturday, April 6
Instruction resumes	Monday, April 15
Spring term instruction ends, 1:10 p.m.	Saturday, May 11
First day of final examinations	Friday, May 17
Last day of final examinations	Monday, May 27
Commencement Day	Monday, June 3

The dates shown in the Academic Calendar are subject to change at any time by official action of Cornell University.

In enacting this calendar, the University Senate has scheduled classes on religious holidays. It is the intent of Senate legislation that students missing classes due to the observance of religious holidays be given ample opportunity to make up work.

Cornell University

College of Engineering

In engineering, a constant factor is change—change so swift that the engineering student must be offered an education that is adaptable and flexible as well as specific. In its long history, the College of Engineering at Cornell has consistently offered such education. Today the College combines undergraduate and graduate education with scientific and engineering research within the context of a diverse and distinguished university, and is thereby continuing its tradition of providing both practical and sound general education.

Engineering courses have been taught at Cornell since the University was founded more than one hundred years ago. At that time, Cornell was regarded as a radical experiment in higher education, teaching subjects like engineering and agriculture as well as the humanities. The University's founder and first benefactor, Ezra Cornell, was convinced, however, that the classics and the more practical "mechanic arts" would thrive together and that the nation needed citizens educated in both. Mr. Cornell had had considerable experience in engineering work; for example, he laid the first telegraph line between Baltimore and Washington for Samuel F. B. Morse. Ezra Cornell made the first clear statement of what is now generally conceived to be the true university concept of higher education, when he said of his University, "I would found an institution where any person can find instruction in any study."

In addition to the College of Engineering, Cornell University has six other divisions to which secondary-school graduates are admitted: Agriculture and Life Sciences; Architecture, Art, and Planning; Arts and Sciences; Hotel Administration; Human Ecology; and Industrial and Labor Relations. Graduate education at Cornell is administered by the Graduate School and by the professional or graduate divisions in law, veterinary medicine, business and public administration, nutrition, nursing, and medicine. All but the last two divisions (which are in New York City) are in Ithaca, New York, on a campus that is generally regarded as one of the most beautiful in the United States.

Engineering students at Cornell, whether graduate or undergraduate, are not only a part of a distinguished engineering college but also a part of the larger University; they may, of course, draw upon the course offerings of other divisions of Cornell. There are no University requirements which force students into the same educational mold. Undergraduate engineering students have a choice of a wide range of specialty programs which can be adapted to meet particular educational and career goals, or they can arrange individual curricula.

Cornell has produced many engineering firsts: It developed the first undergraduate electrical engineering program in the nation and pioneered in the early development of curricula in industrial engineering, mechanical engineering, and engineering physics. In addition, Cornell was the first to award graduate degrees in engineering—the degree of Civil Engineer in 1870 and the first doctorate in civil engineering in 1872. The latter was the first Ph.D. awarded at Cornell in any graduate study. In 1885, the first Ph.D. in electrical engineering was granted, and in 1886, one of the first major national scientific fraternities, Sigma Xi, was founded at Cornell.

Today, approximately 2,100 undergraduate engineers are enrolled in the various schools and departments of the College of Engineering. In addition, about 650 full-time students are working on advanced degrees in areas covering every portion of the engineering profession. Two hundred engineering faculty members are complemented by the faculties in the University's various mathematics and science departments.

The rapid acceleration of the growth of modern science and technology poses a complex and exciting challenge for engineering education. Every division of the College is committed to offering the best possible undergraduate programs and to advancing graduate education and research. In this way, Cornell engineers are provided with the foundation essential for active and rewarding professional careers.

Organization of the College

The College of Engineering offers degree programs at each of the following levels: Bachelor of Science, Master of Engineering, Master of Science, and Doctor of Philosophy. To carry out the aims of each of these degree programs, the faculty of the College of Engineering is organized into schools, departments, and graduate Fields.

Generally, a school or department is responsible for definition and subsequent supervision of the undergraduate curriculum in its area of engineering. In addition, the faculty of a school is responsible for the Master of Engineering degree program.

For Master of Science and doctoral programs the University faculty is organized into graduate Fields. (See p. 11 for those Fields associated with the faculty of the College of Engineering.)

Facilities

Buildings and Laboratories

A complex of modern buildings, most of them on the Engineering Quadrangle, provide accommodations for engineering teaching and research. Several of these buildings have been gifts from distinguished Cornell alumni.

Carpenter Hall houses administrative offices and the Engineering Library.

Bard Hall contains most of the laboratories and classrooms of the Department of Materials Science and Engineering.

Clark Hall serves the University's Department of Physics and houses facilities of the School of Applied and Engineering Physics. It is located on the campus of the College of Arts and Sciences.

Grumman Hall, adjacent to Upson Hall, houses facilities of the Sibley School of Mechanical and Aerospace Engineering.

Hollister Hall houses the School of Civil and Environmental Engineering.

Kimball Hall is used for mechanical engineering laboratories and also houses the Department of Geological Sciences.

Olin Hall houses the School of Chemical Engineering, the offices of the Division of Basic Studies, and the Engineering Advising and Counseling Center.

Phillips Hall is the headquarters of the School of Electrical Engineering.

Thurston Hall facilities are used by the Department of Theoretical and Applied Mechanics and by the Department of Structural Engineering of the School of Civil and Environmental Engineering.

Upson Hall houses the administrative offices and some of the facilities of the Sibley School of Mechanical and Aerospace Engineering; the School of Industrial Engineering and Operations Research; the University's Department of Computer Science; and headquarters of the Laboratory of Plasma Studies. A remote terminal of the University's central computing facility, located in Upson Hall, provides convenient access for engineering students and professors.

Ward Laboratory of Nuclear Engineering houses special equipment including TRIGA and low-power reactors, a gamma irradiation cell, and a low-energy ion accelerator.

More detailed descriptions of facilities for each of the instructional areas in the College may be found within the section Areas of Instruction.

Library Resources

The Engineering Library, in Carpenter Hall, houses approximately 138,000 books and periodicals, a collection which reflects the needs of the many schools and departments of the College of Engineering. Among the specialized holdings of the Engineering Library are a full depository collection of the United States Atomic Energy Commission, a subscription collection of the Rand Corporation publications (established in 1953), and the Water Resources Collection. For patent research, the library maintains sets of the Official Patent Gazette of the United States Patent Office and the Canadian Patent Office Record (patent abstracts), and a file of the British patents.

Allied and supporting literature in the basic sciences is available in the Edna McConnell Clark Library (physical sciences) in Clark Hall and in the Mathematics Library in White Hall. The major collection in the biological sciences will be found in the Albert R. Mann Library, and that for the geological sciences in the John M. Olin Library. The total library resources of the University include more than four million volumes.

Academic Programs

Bachelor of Science Degree

The undergraduate degree of Bachelor of Science is granted by the College of Engineering upon the successful completion of a four-year course of study. The student obtains this degree by spending two years in the Division of Basic Studies preparing for entry into one of seven upperclass *Field Programs* or a *College Program,* in which he will spend two additional years completing the requirements for the undergraduate degree. (An exception is the program in agricultural engineering, which is administered jointly by the College of Engineering and the College of Agriculture and Life Sciences. Students are enrolled in the College of Agriculture and Life Sciences for the first three years, and in the College of Engineering for the fourth year.)

Undergraduate Engineering Curricula

One of the goals of the engineering curricula is to provide a sound educational base which makes possible a wide choice of careers in engineering and applied science.

The usual undergraduate curriculum includes forty courses, giving a minimum of 126 credits, that are divided between the underclass Basic Studies program and the more specialized upperclass program.

The underclass curriculum normally consists of five courses each of four semesters; the twenty courses are distributed as follows:

Two introductory engineering courses
Four mathematics courses
Three physics courses
One chemistry course
Two natural science or social science elective courses
Four engineering core science elective courses (see p. 24)
Four liberal studies elective courses.

After completing the Basic Studies Program, the engineering student enters the Field Program of his choice, or the College Program. The upperclass Field Programs include the following twenty courses.

Four liberal studies elective courses, two of which must be at an advanced level.
Two free elective courses
Two technical elective courses
Twelve Field-designated courses.

Upperclass students who enter the College Program must meet similar requirements (see p. 36).

Field Programs available for the junior- and senior-year specialization are:

Chemical Engineering (see p. 32).
Civil and Environmental Engineering (see p. 33).
Electrical Engineering (see p. 40).
Engineering Physics (see p. 27).
Industrial Engineering and Operations Research (see p. 44).
Materials Science and Engineering (see p. 47).
Mechanical Engineering (see p. 51).

The College Program (see p. 36) is a flexible and individually structured curriculum which is offered so as to accommodate educational objectives not served by one of the Field Programs. Bioengineering-oriented curricula are available in most Field Programs and in the College Program to accommodate the interests of students who plan to apply their engineering skills in biological areas.

Elective courses may be chosen from the offerings of any division of the University. For information on particular courses of interest, students and their advisers consult other *Announcements,* most frequently those of the College of Arts and Sciences, the College of Agriculture and Life Sciences, the School of Industrial and Labor Relations, and the College of Human Ecology. A listing of subjects of study offered in the various units of the University, and the schools or colleges which offer them, is given in the *Announcement of General Information.*

The Engineering Cooperative Program

The basic premise of the Engineering Cooperative Program at Cornell is that industry can play a major role in a student's education by providing him with work assignments appropriate to his interests and training. Under this Program an undergraduate engineering student can obtain almost a full year of professional experience without extending the date of his graduation. More than 600 Cornell engineers have participated in this Program since its inception in 1947.

Students enrolled in the Program spend alternating periods in college and in industry after the sophomore year. By utilizing the three summers that follow completion of the sophomore year, three work periods, totaling nearly a calendar year, are provided. On the following schedule they are designated I, II, and III, respectively.

Summer	Fifth Term Courses
Fall (Junior Year)	Industry I
Spring (Junior Year)	Sixth Term Courses
Summer	Industry II
Fall (Senior Year)	Seventh Term Courses
Spring (Senior Year)	Eighth Term Courses
Bachelor of Science Degree	
Summer	Industry III

By the end of the summer following his graduation, the student is ready to accept a professional position or begin graduate work. Graduate study leading to the Master of Engineering degree can, for example, begin in the fall term.

While on a work assignment, the student earns a substantial salary and gains industrial experience that complements classroom knowledge and facilitates the transition from college to industry. Because the Program emphasizes the development of the individual and his abilities, the student works for only one company during the three industry periods. However, neither the student nor the company is obligated in any way after completion of the Program. Having participated in the Program, the graduate can expect his initial level of responsibility and salary to be greater than he might otherwise receive.

Companies participating in the Engineering Cooperative Program include the following: American Electric Power Service Corporation; AVCO Everett Research Laboratory; Chicago Pneumatic Tool Company; Clairol Incorporated; Corning Glass Works; Eastman Kodak Company; Eaton Corporation; Emerson Electric Company; General Electric Company (Schenectady, New York, Syracuse, New York, and other locations); The Gleason Works; Hewlett-Packard Company (New Jersey Division and Medical Electronics Division); International Business Machines Corporation; Moore Products Company; The Procter & Gamble Company; Raytheon Company; Sanders Associates, Inc.; S. I. Handling Systems, Inc.; and Xerox Corporation.

Admission to the Program is open to any fourth-term student who has chosen electrical engineering, engineering physics, industrial engineering and operations research, or mechanical engineering as his Field and who meets the following requirements: (1) a sound scholastic performance at the time of admission to the Program; and (2) an invitation from one of the participating companies based on an individual interview.

Further information about the Program may be obtained from the Engineering Cooperative Program Office, 138 Upson Hall.

Program for Minority Students

There are now about 135 minority students, largely black, among the approximately 2,100 College of Engineering undergraduates, and efforts are being made to increase this proportion. Because deficiencies in preparatory work and other background handicaps often exist among these students, the College offers special programs to aid them in their completion of an engineering curriculum and the preparation for a professional career.

Among available support services is a summer orientation program designed to strengthen skills in mathematics and science. It precedes freshman matriculation. During the regular academic year, special advising and counseling services are offered in coordination with the University's Committee for Special Educational Programs (COSEP). Tutoring is available, and provisions are made for reducing academic loads where this seems advisable. In addition, two programs are offered to help orient the students to engineering as a profession. One brings practicing minority-group engineers to the campus in a special series of lectures and discussions, and the other provides sophomores with the opportunity to participate in "on the job" industrial experience for a short period of time between academic terms.

Admission of minority-group students, as of all applicants, is considered partly on the basis of academic performance in high school and of scores on college entrance examinations and achievement tests. Test scores are analyzed in terms of the applicant's environmental background. Subjective information from Cornell alumni, school guidance counselors, community agency personnel, and other concerned individuals is also considered.

Complete financial assistance, in the form of scholarships and loans, is available to all minority students (see p. 17).

Study in France: an Exchange Program

Junior engineering students are eligible to participate in a student exchange program which the College of Engineering operates with several engineering schools in France. The program was first begun a number of years ago with the École Nationale Supérieure de Méchanique et d'Aérotechnique (ENSMA) in Poitiers (about 150 miles southwest of Paris). ENSMA, a small school with a total student body of around 170, is closely associated with a large university in Poitiers. Its principal specialties are mechanical, thermal, and aerospace engineering; and there is also an emphasis on computer use and technology. Recent Cornell participants have included some students in the College Program and some majoring in engineering physics and mechanical engineering.

The exchange program is now being extended to other engineering schools in France so that all of the fields of engineering study offered at Cornell may be pursued in France, during the junior year, without any important curricular problems. Among the newly participating institutions in France are several of the five schools grouped in the Institut Polytechnique de Grenoble, in Grenoble. Cornell will continue to send each year only a few students, at the most, to any one school.

Because the Cornell exchange students live in small groups among French students and take their instruction entirely in French, facility in the language is essential. Some of the Cornell participants have spent one or two months during the preceding summer at a language school in France.

The Program is coordinated by Professor Benjamin Gebhart, 224 Upson Hall.

Preparation for Graduate Study

The Bachelor of Science degree in a Field Program or a College Program may be the terminal point in the formal education of some students; however, it is expected that most will wish to continue studies beyond this level.

Upon completion of the undergraduate degree requirements, a student may apply for admission to the College's professional Master of Engineering degree program and can earn that degree in one additional year.

The degree requirements include advanced work begun formally during the junior year, and thus the degree represents a three-year program of integrated studies in a particular field. The program is designed to meet the requirements of modern engineering practice, and the professional master's degree represents the level at which graduates will be prepared to seek professional engineering employment.

Individuals seeking careers in research, in applied science, or in a specialized engineering area, such as thermal engineering within mechanical engineering, can apply for the Master of Science or the Doctor of Philosophy program at the end of the four-year baccalaureate program. Some students may want to undertake graduate or professional study in other areas such as education, law, business, public administration, city and regional planning, or medicine.

Master of Engineering Degree

Graduates intending to prepare for professional engineering careers generally seek the professional degree of Master of Engineering (with Field designation.) At Cornell this one-year program is integrated with the undergraduate engineering program; after receiving their baccalaureate degrees, many students apply to continue for the fifth year. Applications from engineering graduates of other institutions are also encouraged.

The degree may be taken in any of the following areas:

Aerospace Engineering (see p. 49).
Agricultural Engineering (see p. 26).
Chemical Engineering (see p. 32).
Civil Engineering (see p. 34).
Electrical Engineering (see p. 42).
Engineering Mechanics (see p. 57).
Engineering Physics (see p. 29).
Industrial Engineering (see p. 46).
Materials Engineering (see p. 47).
Mechanical Engineering (see p. 52).
Nuclear Engineering (see p. 54).

The professional degree requires a minimum of thirty credit hours of graduate-level work in the principles and practices of the specific field. It does not require the presentation of a thesis. It does, however, require completion of an engineering design project that may be worked on individually or in groups of up to four students, and submission of a formal report on the project. The program also requires completion of a curriculum of related technical courses, differing in content among the several professional Fields. Each curriculum includes some prescribed and some elective courses, with considerable flexibility to permit adaptation to the special needs of the individual student. A cumulative grade-point average of at least 2.5 is required for admission and for good standing in the program, and for recommendation for the degree.

Master of Science and Doctor of Philosophy Degrees

The general degrees of Master of Science and Doctor of Philosophy are oriented toward students seeking academic or research careers. They require submission of a thesis on research conducted under the direction of a faculty member. Details of admission, residence requirements, and financial aid are given in the *Announcement of the Graduate School* (see p. 4 for the address).

Programs of study are organized under graduate Fields, most of which coincide with the respective engineering schools or departments. Descriptions of the various Fields may be found in the illustrated *Announcement, Graduate Study in Engineering and Applied Science* (see p. 4 for address). The *Announcement* includes a description of each Field, in terms of academic programs, professional opportunities, the facilities available at Cornell, the research projects currently under way, and the faculty members and their research interests. Prospective candidates whose interests are already well defined are invited to communicate with the appropriate graduate Field representative.

The graduate Fields that may be of interest to engineering students are listed below, with associated major and minor subject areas.

Aerospace Engineering: Aerospace Engineering, Aerodynamics

Agricultural Engineering: Agricultural Engineering, Agricultural Structures, Agricultural Waste Management, Electric Power and Processing, Power and Machinery, Soil and Water Engineering

Applied Mathematics

Applied Physics

Chemical Engineering: Biochemical Engineering, Chemical Engineering (General), Chemical Microscopy, Chemical Processes and Process Control, Materials Engineering, Nuclear Process Engineering

Civil and Environmental Engineering: Aerial Photographic Studies, Environmental Systems Engineering, Geodetic and Photogrammetric Engineering, Geotechnical Engineering, Hydraulics and Hydrology, Sanitary Engineering, Structural Engineering, Structural Mechanics, Transportation Engineering, Water Resource Systems

Computer Science: Computer Science, Information Processing, Numerical Analysis, Theory of Computation

Electrical Engineering: Electrical Engineering, Electrical Systems, Electrophysics

Geological Sciences

Materials Science and Engineering: Materials and Metallurgical Engineering, Materials Science

Mechanical Engineering: Machine Design, Materials Processing, Thermal Power, Thermal Processes

Nuclear Science and Engineering: Nuclear Engineering, Nuclear Science

Operations Research: Applied Probability and Statistics, Industrial Engineering, Information Processing, Operations Research, Systems Analysis and Design

Theoretical and Applied Mechanics: Fluid Mechanics, Mechanics of Materials, Solid Mechanics, Space Mechanics

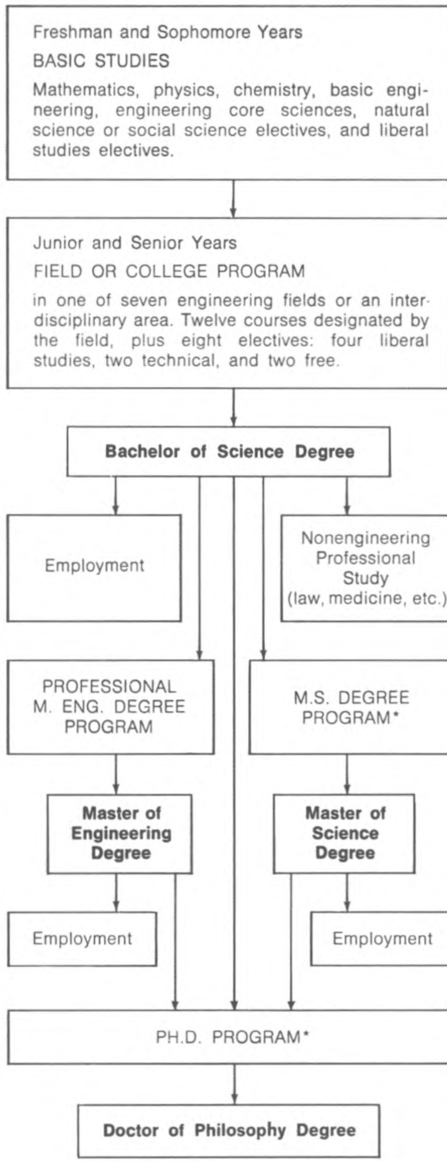
Water Resources

Continuing Education Activities

The College's Office of Continuing Engineering Education provides special programs for engineers and scientists in industry, research institutes, private practice, government agencies, and colleges and universities. The growing flood of technical information makes it impossible for the average engineer to keep his knowledge current except perhaps in a narrow specialty. Many engineers rise to positions in technical management in which they must direct the activities of a variety of specialists. For such work they must be conversant with the concepts and vocabulary of many different disciplines. Because of the constant changes in undergraduate and graduate curricula, the manager who is ten years out of school often finds it difficult to communicate effectively with newly graduated engineers even within his own specialty. Unless given opportunities to update his knowledge, the engineer will soon find his professional abilities inadequate.

Cornell programs to provide these opportunities include: in-plant courses for firms in the Ithaca area; short courses and workshops in various technical subjects; and programs for specific industries. No academic credit is given for most of the programs.

Summary of Programs and Options in Cornell Engineering Education



* Consult the *Announcement of the Graduate School* for detailed requirements for the M.S. and Ph.D. degree programs.

Courses entitled Modern Engineering Concepts for Technical Managers are offered annually, both in the plant and on the Cornell campus. These courses consist of thirty to fifty lecture-seminars on topics in mathematics, materials science, operations research, electronics and solid state devices, nuclear engineering, bioengineering, and other areas. The courses emphasize breadth, not depth, and provide a resource from which to draw ideas and direction for effective technical management.

Intensive short courses, three days to two weeks long, are offered in various technical subjects each summer. In twelve courses offered in 1973, subjects included: computer science; structural design; control of water-borne wastes; finite element analysis; electron microscopy; reliability in mechanical components; and other related topics. Participants include both alumni of Cornell and nonalumni who come from many different states and foreign countries.

Further information about any of these programs may be obtained from the Office of the Director of Continuing Engineering Education, Carpenter Hall.

Admission

It is the policy of Cornell University actively to support equality of educational opportunity. No student shall be denied admission to the University or be discriminated against otherwise because of race, color, creed, religion, national origin, or sex.

Freshman Admission

The Office of Engineering Admissions in Carpenter Hall is the focal point in the College for the admission of freshman and transfer students and for the administration of the engineering scholarship funds.

Detailed information concerning the procedures of undergraduate admission is given in the *Announcement of General Information* and in the *Guide for Candidates* (included with each application form). Important dates for applicants include:

Admission applications due: Regular, February 15; Early Decision Plan, November 1.

Admission decisions announced: Regular, as decisions are made in February, March, and the first half of April; Early Decision Plan, December 1 (except that those who are considered on the basis of November College Entrance Examination Board Scholastic Aptitude Tests will be notified by mid-December—the scores are not received by the Office of Engineering Admissions until early in December.)

Financial aid applications due: Regular, January 15; Early Decison Plan, November 1.

Financial aid decisions announced: Regular, by mid-April; Early Decision Plan, December 1.

Date by which applicant must advise Cornell of his decision (for admission *and* financial aid): Regular, May 1; Early Decision Plan, applicants will be advised of date.

Secondary School Credits

Sixteen units of college-preparatory subjects are required. The following fourteen units must be included:

Subject	*Units**
English	4
History	2
One foreign language	2
Algebra (elementary and intermediate)	2†
Plane geometry	1†
Trigonometry	½†
Advanced algebra or solid geometry	½†
Chemistry	1
Physics	1

* A unit is one year of study, made up of 120 hours of classroom work; that is, a minimum of 160 class periods if each is forty-five minutes long.

† The mathematics units listed above may be taken as separate courses or may be included in four units of comprehensive college-preparatory mathematics.

College Entrance Examinations

Each candidate is required to take standardized college admissions tests so that scores can be considered by the Engineering Admissions Committee. There are two available alternatives.

One alternative is for the student to take the College Entrance Examination Board Scholastic Aptitude Test (SAT), and in addition the Achievement Tests in mathematics (Level I or Level II) and in chemistry or physics. These *must* be taken not later than January of the last year in secondary school. Generally, it is recommended that the Achievement Test in science be taken in May of the junior year, in that science in which the applicant is then enrolled. However, the Engineering Admissions Committee will consider a science Achievement Test that is taken in December or January of the senior year for a course completed in the junior year, or earlier, or for a course currently in progress. Under these circumstances, test results are not expected to be as high as the results of tests taken at the time of completion of a full year's work. *Applicants should not defer this required test until March or May of the senior year, for results would be received too late to be useful to the committee.*

The other alternative is to submit American College Testing Program (ACT) scores. The ACT tests should be taken not later than the December test date.

Other Factors

Three factors are considered in the review of each candidate. The first factor is academic and includes, in addition to the college entrance examination results, the applicant's high school grades, rank in class, and other available academic data. The second and third factors are personal qualities and demonstration of a well-considered desire and well-founded commitment to study engineering.

Personal qualities that are considered may include leadership capabilities and intellectual creativity. Significant participation in extracurricular activities and recommendations by counselors may also be considerations. A student's commitment to engineering is evidenced by the extent of his investigation of the field and his understanding of the implications of an undergraduate professional education.

The admissions committee tries to judge whether a student has the maturity and the study and work habits that are necessary for success in an engineering curriculum. Superior grades or high college entrance examination scores are in themselves no guarantee of success, nor are they alone a guarantee of admission.

Advanced Placement

Normally about one-fifth of the students entering the College of Engineering as freshmen receive advanced placement and credit toward the B.S. degree. This is earned most often in mathematics, physics, and chemistry, but it is also received in other subjects such as biological science, history, and foreign languages. In some cases it is possible for students to complete the undergraduate degree requirements in less than the usual four years (see also p. 20).

Advanced placement credit may be obtained by entering freshmen in three ways. The most common way is by achieving high standing in College Entrance Examination Board Advanced Placement tests. A second way is by performing well on advanced placement examinations that are given by a number of Cornell departments during the fall orientation period, or by meeting certain departmental requirements. Finally, secondary school students may receive Cornell credit for course work completed at local, accredited colleges and universities. Normally, credit toward the Cornell degree will be awarded if the following conditions are met: (1) The college course was not taken to satisfy secondary school graduation requirements; (2) the course is registered on an official transcript from the college or university; (3) the course is applicable to some portion of the Cornell undergraduate engineering curriculum.

Advanced Credit for Engineering Students, a publication that describes advanced credit possibilities in various subjects at Cornell, may be requested from the Office of Engineering Admissions, 223 Carpenter Hall. The requirements for advanced credit in four subject areas are summarized below.

Mathematics. If possible, secondary school students should take one of the two College Entrance Examination Board Advanced Placement examinations in mathematics during the senior year. For engineering students, a grade of 3 or higher on the AB examination, or of 2 or 3 on the BC examination earns advanced placement credit for Mathematics BMA191 and placement in Mathematics BMA192. A grade of 4 or 5 on the BC examination will result in advanced placement credit for Mathematics BMA191 and BMA192 and placement in Mathematics BMA293.

Students who did not take one of the College Board examinations, or who took one but received less advanced placement than they think they should have, may take a special placement examination which is given by the Cornell Department of Mathematics just before the beginning of classes in the fall.

Physics. Entering freshmen who have scored well on a College Board Advanced Placement examination in physics may be granted advanced placement credit for Physics BPS112, the first of the required three-course sequence in physics. It should be noted, however, that the mathematics prerequisites for physics courses must be satisfied, and that an accelerated program in physics is therefore contingent on advanced placement in mathematics.

Suitably prepared students who did not have the opportunity to take the College Board examination may take instead a special test administered by the Cornell Department of Physics in the fall (and also in June for students enrolled in the Cornell Summer Session). Suitable preparation for this departmental test consists of two years of secondary school physics.

Chemistry. A score of 4 or 3 on the College Board Advanced Placement examination in chemistry earns three hours of advanced placement credit for Chemistry BCH207, and a score of 5 earns an additional four hours of credit for Chemistry BCH208. It is also possible for a student to achieve advanced placement credit by passing a special examination for Chemistry BCH207–208. Arrangements for taking this examination must be made with the Department of Chemistry. Students who earn one term of advanced placement in chemistry are not required to take additional chemistry unless they intend to major in chemical engineering.

Biological Sciences. Engineering students who are planning to take advanced courses in biological sciences and who achieve a score of 3 or 4 on the College Board Advanced Placement examination in biology will be placed in a special honors section of Biological Sciences OBA101–102. Students who receive a score of 5 will be given six hours of advanced placement credit in biology, which may be used to satisfy the natural sciences requirement.

Transfer Admission

The College of Engineering welcomes inquiries about transfer opportunities for students who are currently attending other four-year or two-year colleges and universities. Each year the College matriculates approximately one hundred new transfer students, and it is actively seeking to increase this number. Interested students are invited to communicate with the Chairman, Transfer Admissions Committee, 221 Carpenter Hall.

Transfer students are admitted at the junior-year level or below. Because the transfer student must satisfy the same degree requirements as all other Cornell engineers, admission is usually offered only to those candidates who have excelled in academic programs comparable, both in course content and rigor, to the College's own curriculum. The Cornell engineering curriculum for the freshman and sophomore years is discussed under Basic Studies (see p. 23). Detailed course descriptions begin on p. 60.

Students who are accepted for transfer admission but are found deficient in the specific course work required for a given level of placement may be asked to attend a summer session at Cornell or elsewhere in order to complete this work prior to matriculation at Cornell. Transfer candidates are encouraged to prevent such course deficiencies by consulting with the Transfer Admissions Committee as early as possible so that academic schedules may be planned to parallel Cornell's underclass program.

Students who are accepted for transfer on the basis of completion of two terms or three quarters of academic work with better-than-average records in other collegiate institutions will be awarded credit for thirty-three hours. However, there may be a stipulation that certain courses normally taken in the freshman year be completed as free electives before graduation. Similarly, above-average students who are accepted on the basis of completion of four terms or six quarters in other institutions will be awarded credit for sixty-six hours, with the possible provision that certain underclass courses be completed as free electives before graduation. In the case of students who are accepted for transfer admission but have only average academic records, individualized course credit evaluations will be made. University policy prohibits the granting of transfer credit for any course for which the student received a grade below C–.

Since 1968, the College of Engineering has offered Junior and Community College Scholarships to United States citizens who are currently enrolled in community or junior colleges and have been accepted for transfer admission to the College. As with all financial assistance, the amount of these special scholarships varies with each individual, depending upon his demonstrated financial need. A Parents' Confidential Statement (PCS), available from the College Scholarship Service at Princeton, New Jersey, must accompany the scholarship application.

Students who apply for transfer from other four-year colleges and universities cannot be considered for financial aid until they have completed one term in residency at Cornell.

Applications for transfer admission for the fall term beginning in September will be accepted until August 1, although April 15 is the preferred date, especially for those interested in the special scholarships for two-year college students. Candidates who wish to be considered for midyear transfer should make application by December 1.

International Students

The College of Engineering encourages highly successful foreign students to consider the opportunities available at Cornell. Each year the College matriculates approximately thirty-five freshman students of foreign nationality. Students interested in admission to any Cornell division should communicate with the Undergraduate Admissions Adviser, International Student Office, Barnes Hall.

Special Students

In exceptional cases, individuals who do not wish to become candidates for an undergraduate degree may be admitted as special students. Persons who cannot meet the usual entrance requirements or who do not wish to spend the time required to complete a degree may qualify, but they must have had some engineering training and must satisfy the prerequisites for the courses they wish to take. Other applicants may have baccalaureate degrees but wish to pursue further work at the undergraduate level. In any case, a prospective special student should write to the director of the professional school to which he wants to be admitted.

Graduate Admission

An applicant for admission to a graduate degree program in engineering must hold a baccalaureate or equivalent degree from a college or university of recognized standing. Such a

student may enter as a candidate for either of the general degrees (Master of Science or Doctor of Philosophy) or for the professional engineering degree—Master of Engineering (Aerospace, Agricultural, Chemical, Civil, Electrical, Engineering Mechanics, Engineering Physics, Industrial, Materials, Mechanical, or Nuclear).

Professional Master's Degree

Any student with a baccalaureate degree in the area of engineering or science that is deemed appropriate for his proposed field of study may become a candidate for the professional degree of Master of Engineering (with Field designation), which is described on p. 11. A Cornell graduate will generally be admitted if he has a cumulative grade-point average of at least 2.5 and/or if he has demonstrated by his performance in his major field that he has the ability to be successful in graduate study. A petition is required if the grade-point average is below 2.5. Graduates of schools other than Cornell must provide evidence of adequate undergraduate preparation: a transcript, two letters of recommendation, and a statement of academic purpose.

Further information and application forms may be obtained by writing to Graduate Professional Engineering Programs, College of Engineering, 221 Carpenter Hall, or to the program chairmen for the various fields. While there is no specific deadline for the receipt of applications, early submission is recommended, especially if the candidate wishes to apply for financial aid. The deadline for financial aid application is February 1.

General Degrees

The Master of Science and Doctor of Philosophy degrees, administered by the Graduate School, are available in all Fields and subdivisions of the College of Engineering (see pp. 11–12). They require work in both major and minor areas of study, as well as the completion of a satisfactory thesis, usually involving individual and original research. A prospective graduate student interested in obtaining an M.S. or Ph.D. degree should consult the *Announcement of the Graduate School* for additional information concerning these degrees and should correspond with the professor supervising the particular area of engineering representing his major interest. Students who do not completely meet the entrance requirements for these degrees may be admitted as provisional candidates or without candidacy according to previous preparation, but they must in all cases hold a baccalaureate or equivalent degree.

Finances

Expenses

Estimated expenses for a student in the College of Engineering for the 1973–74 academic year total $5,400, which includes $3,180 for tuition and fees, an estimated $1,500 for room and board, $670 for personal expenses, and the $50 registration fee.

Additional details concerning these expenses, method of payment, refunds, and other matters of financial interest are given in the *Announcement of General Information.*

Undergraduate Financial Aid

Substantial aid in the form of scholarships, loans, and employment is available to help students meet the cost of their education. Over two-thirds of all undergraduate engineering students receive financial aid, and the total resources available for these students amount to about $1.75 million a year.

Freshman Applicants

More than $600,000 in scholarship grants will be awarded this year to College of Engineering freshmen. Loans and jobs will increase the total amount of financial aid for engineering freshmen to about $700,000. The College follows a policy of full-need awards; that is, no award will be made unless a package of scholarship, loan, and occasionally a job can be provided to equal calculated need. The total financial aid package may be as high as $4,900 a year. Awards made to freshmen are normally continued through four years, contingent on continuance of the calculated need.

Freshmen seeking financial aid should complete the financial aid application form and file it, still attached to the admissions application, with the University Office of Admissions. The Parents' Confidential Statement of the College Scholarship Service must also be filed.

No student should refrain from applying for admission because of financial circumstances. Admissions decisions are rendered without regard for financial aid requirements; after admission has been granted, applicants for financial aid are considered for the available funds.

Upperclassmen

For upperclassmen who *did not* receive aid as incoming freshmen, there are extremely limited sources of financial aid. The appropriate application forms may be obtained from the University Office of Scholarships and Financial Aid.

Transfer Students

During the past four years, the College of Engineering has enrolled increasing numbers of transfer students from junior and community colleges and has made the transition to Cornell financially possible by means of special Community and Junior College Scholarships. The availability of these funds makes Cornell, a private institution, as economically feasible as most publicly supported engineering schools.

In the past few years, all accepted two-year college transfer candidates of United States citizenship have been awarded financial aid commensurate with need as demonstrated by the student's financial aid application. Junior and community college students interested in Cornell engineering and this special scholarship program are invited to communicate with the Chairman, Transfer Admissions Committee, 221 Carpenter Hall.

Scholarship Resources

The largest single source of assistance for engineering students is the John McMullen Scholarship Fund. In any given year more than 500 undergraduates receive support from this fund; total expenditures for their scholarships exceed $1 million annually.

The McMullen Fund and other major resources which provide scholarships specifically for engineering students are listed in the chart, pp. 18–19. Each applicant files only one application. The Engineering Scholarship Committee attempts to assign specifically designated awards to those students whose qualifications most nearly match the donor's wishes.

In addition to these special engineering scholarships, there are University-wide scholarships for which accepted engineering applicants are eligible. These include the Cornell National Scholarship and the General Motors Scholarship.

Graduate Financial Aid

Financial aid to graduate students is available in several forms: fellowships and scholarships; research or teaching assistantships; residence hall assistantships; and loans. Applicants for the M.S.–Ph.D. program who wish to be candidates for financial assistance should consult the *Announcement of the Graduate School* and make application to the dean of the Graduate School.

Those who are candidates for the professional degree programs and wish to apply for financial aid should complete a special application form available along with the admission application form through the various program chairmen, or from the office of the Graduate Professional Engineering Programs, 221 Carpenter Hall.

Scholarship Resources

Donor	*Designated Engineering Field*	*Number of Awards (All Classes)*	*Amount per Award*
Alcoa Foundation Scholarship	Any	5	$ 750
Charles R. Armington Scholarship	Any	6	2,000 max.
John Henry Barr Scholarship	Any	1	2,000 max.
Seymour L. Baum Memorial Fund	Electrical Engineering	1	200
Robert H. Blackall Scholarship	Any	3	1,250*
Edward P. Burrell Scholarship Endowment	Primarily for Women	10	1,300*
Carrier Memorial Scholarship	Any	3	1,200
Redmond Stephen Colnon Scholarship Endowment	Any	1	1,500
The *Cornell Engineer* Scholarship	Any	1	Variable
Casper L. Cottrell Scholarship Fund	Electrical Engineering	1	800
Calvin H. and Della N. Crouch Endowment	Mechanical Engineering	1	500
A. Clinton Decker Memorial Scholarship	Any	5	900*
Warren V. Delano Memorial Endowment	Mechanical Engineering	1	450
Otto M. Eidlitz Scholarship Endowment	Any	2	900*
Joseph H. Evans Endowment	Any	1	250
C. Harold Fahy Scholarship Endowment	Civil Engineering	1	700
Elbert Curtiss Fisher Scholarship	Any	1	1,200
Carl R. Gilbert Memorial Endowment	Any	1	350

Donor	*Designated Engineering Field*	*Number of Awards (All Classes)*	*Amount per Award*
Emmet Blakeney Gleason Scholarship Fund	Various Specified Fields	1 or more	2,200 max.
Paul G. Haviland Memorial Scholarship	Any	1	1,000
Hayward Headden Memorial Scholarship	Mechanical Engineering	1 or more	Variable
Howard Elmer Hyde Civil Engineering Scholarship	Civil Engineering	1	300
Martin J. Insull Scholarship Endowment	Any	2	1,100*
Albert Jadot Memorial Scholarship Endowment	Foreign Students	1	600
Chester H. Loveland Engineering Scholarship Fund	Civil Engineering	1	1,500 max.
The Charles McAllister '87 Endowment	Any	1	350
Harrison D. McFaddin Scholarship Endowment	Any	4	1,000*
John McMullen Scholarship Fund	Any	600*	2,000*
Moog, Incorporated Scholarship	Any	1	3,100 max.
Robert C. Newcomb Scholarship Fund	Any	3	950*
Niagara Machine and Tool Works Scholarship	Mechanical Engineering	1	1,000
Frank William Padgham Scholarship Endowment	Mechanical Engineering	1	200
Annie F. and Oscar W. Rhodes Scholarship Endowment	Any	15	1,100*
Huldah Jane Rice Scholarship Endowment	Any	5	1,800*
Rohm & Haas Company Scholarship	Chemical Engineering	1	1,000
Scott Paper Company Foundation Award	Any	2	1,000
Frederick B. Scott Scholarship Fund	Any	1	1,000
Sylvester Edick Shaw Scholarship Endowment	Any	1	300
Judson N. Smith Scholarship Endowment	Civil Engineering	1	300
Stauffer Chemical Company Scholarship	Chemical Engineering	1	1,000
William Delmore Thompson Scholarship Endowment	Mechanical Engineering	1	100
Leon C. Welch Scholarship Fund	Any	1	800
Arthur Mellon Wellington Scholarship Fund	Any	1	700
John L. Wentz Scholarship Endowment	Any	1	400
Western Electric Fund Scholarship	Any	11	1,000
Henry G. White Scholarship	Civil Engineering	1	2,000
Jessel Stuart Whyte Scholarship Endowment	Mechanical Engineering	2	1,500*
Wilson Endowment	Mechanical and Electrical Engineering	1	300
Wyman-Gordon Company Scholarship	Materials Science and Engineering	1	1,000

* Range variable. Figure given is the mean.

Academic Standing

Grades

The faculty grades on a letter scale (A through F), refined by the use of + or −. In order to compute averages, grade points are assigned as follows:

A+ = 4.3	A = 4.0	A− = 3.7
B+ = 3.3	B = 3.0	B− = 2.7
C+ = 2.3	C = 2.0	C− = 1.7
D+ = 1.3	D = 1.0	D− = 0.7

No grade points are given for failing (F) grades. Grades of Satisfactory (S) or Unsatisfactory (U) are sometimes given, but they are not included in grade-point-average computations.

In any term after his first semester of freshman residence, an undergraduate may take one or two liberal or free elective courses on an S-U grading basis upon approval of his faculty adviser and the course instructor. The S-U option enables an engineering student to take advanced courses or courses primarily for those majoring in other areas without affecting his grade-point average.

Evaluation and Academic Action

The academic standing of each student is evaluated at the end of each semester by the Admissions and Standards Committee of the College. To be considered in good standing for the semester, a student in the Division of Basic Studies must successfully complete at least twelve credit hours, receive no grade of F or U, and attain the required minimum grade-point average. The minimum acceptable first and second semester grade-point average is 1.7; for the third, fourth, and any additional semesters in the Division of Basic Studies, the minimum is 2.0.

A student who is not in good standing will receive an official warning, will be suspended, or will be prohibited from further registration in the College. An official warning is notice that academic performance is not satisfactory, and that failure to attain good standing the following semester may result in suspension. Except in unusual cases, a first semester freshman not in good standing will be warned. A suspended student must present evidence that he can successfully complete an academic program in the College of Engineering to be considered for readmission.

Honors

Honors sections are available in a number of freshman and sophomore courses. Entrance to these sections is based on the quality of work in the preceding term.

To attain the Dean's Honor List for any term in the College of Engineering, an undergraduate must have attained a term average of at least 3.25, based on at least twelve credit hours in which grades other than S and U have been awarded.

To graduate with Distinction a student must have a 3.25 cumulative average for all his undergraduate courses at Cornell.

Advanced Placement

It is possible for students to obtain academic credit toward the undergraduate degree by taking special high school courses or by achieving sufficiently high scores on special examinations. Details of the advanced placement program as it pertains to entering freshmen are given on p. 14.

Earning advanced credit allows a student to develop a more individualized program of study with a broader liberal component or additional technical courses; it is not normally used to reduce the academic program of any term.

Another possibility available to superior students is to complete a program leading to the B.S. degree in less time than the usual four years or eight terms through a combination of advanced placement credit and summer study. Students who gain advanced placement credit for two terms of mathematics and for chemistry or physics stand a good chance of shortening the time required for graduation.

Entering students who are interested in advanced placement are invited to correspond with the Chairman, Engineering Admissions Committee, 223 Carpenter Hall. Students already enrolled should consult their advisers.

Student Personnel Services

Advising and Counseling

The College of Engineering advising services are designed primarily to provide students with information and counseling in areas that affect their academic and professional development.

Advice on curricular choices and career planning is provided mainly through the faculty adviser, who helps each advisee plan his educational program and is responsible for overseeing the student's academic progress. The faculty adviser also serves as a personal counselor who will direct the student to the appropriate University resource when a particular need arises. Faculty advisers are assigned to matriculating students on the basis of indicated mutual interests; underclassmen may change advisers if their interests change. Upperclassmen are normally served by faculty advisers in their area of specialization. It is essential that students make full use of this important resource on a regular basis.

The College operates the Engineering Advising and Counseling Center in Olin Hall, where students may consult with the Director of Advising and Counseling or with student staff members representing each of the upperclass Fields. These students are particularly helpful in providing underclassmen with peer counseling on the nature of the work in various Fields. Special programs to assist students in selecting their upperclass Field are offered by the Center at various times during the year.

A list of tutors is available at the Center, and group tutorials are arranged by the staff as the need arises. The student staff members will help individual students with short-term tutoring assistance while they are on duty in the Center. Also available at the Center is a wide variety of printed material, including publications of the College of Engineering. A monthly bulletin, *News Briefs,* containing information on various academic activities and programs, is distributed by the Center to all freshmen and sophomore engineering students.

Special counseling services for minority-group students are available through the Director of Engineering Minority Programs.

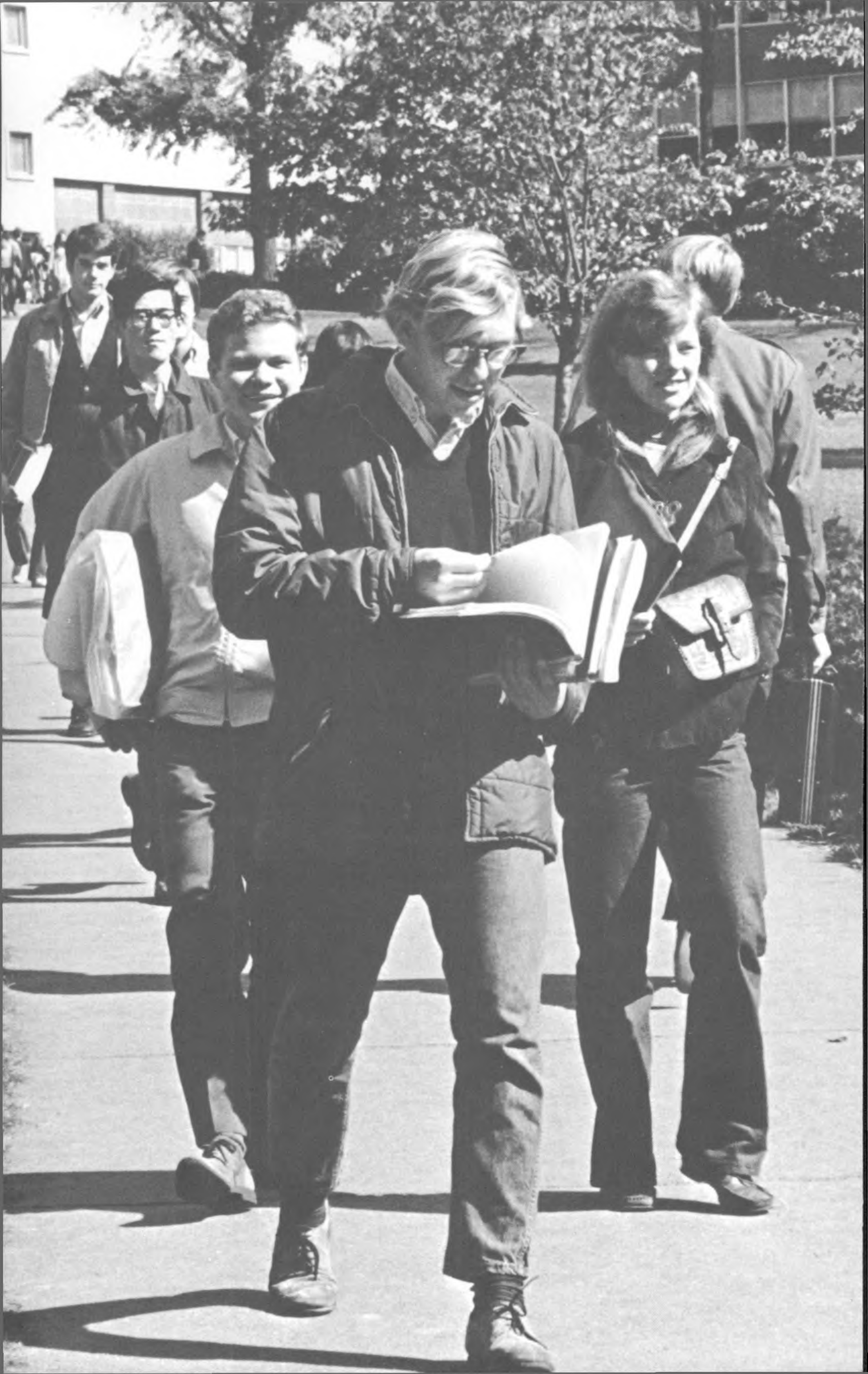
The University provides extensive resources to supplement the advising programs of the colleges. Facilities available to all students include the Office of the Dean of Students, the University Health Service, the Reading-Study Center, the University Guidance and Testing Center, the Office for Coordination of Religious Affairs, the Career, Summer Plans, and Placement Center, and the Office of Scholarships and Financial Aid.

Engineering students not only have access to these organized counseling services of the College and University, but are also welcome to confer with the administrative staff of the College of Engineering, department chairmen, and faculty members on any educational or personal matter.

Placement

The facilities of the University Career, Summer Plans, and Placement Center in Sage Hall are available to all engineering students seeking summer or permanent employment. The College of Engineering also provides placement service through its Office of Student Placement in Carpenter Hall. Information about companies is available at either of these offices, and students may discuss specific employment opportunities and the procedures of job placement with the staff of either office.

The Office of Student Placement, in cooperation with the University's placement services, arranges annual interviews between students and prospective employers. Selected engineering faculty members serve as placement advisers with whom students may discuss their career objectives and plans for employment or graduate study.



Areas of Instruction

Basic Studies

Olin Hall

M. S. Burton, director; G. D. Meixel, Jr.,

Courses of study are listed on pp. 60–65.

Students in the College of Engineering are enrolled for the first two years of their undergraduate education in the Division of Basic Studies, which administers the program of courses for freshmen and sophomores.

Course Requirements

Students are enrolled for five courses each term. Many of these are elective, but the underclass program must be planned so as to satisfy certain requirements. A sequence of four courses in mathematics and a three-term sequence in physics are required of all undergraduates. Freshmen enroll in chemistry during the first term and should elect a second term of chemistry if they plan a chemistry-related upperclass program.

A two-term sequence in engineering subjects IBE105 and IBE106 is required of freshmen. Included is instruction in the computer language PL/I and an introduction to engineering design and graphics. Also, each student chooses two six-week "mini courses" which focus on different engineering fields and include a variety of activities, such as design or laboratory projects, field trips, discussion groups, and case studies of engineering-related problems and issues. Students interested particularly in bioengineering or bioengineering-premedicine may substitute a biology course for IBE106.

All engineering students are required to complete eight liberal studies courses (24 credits) before graduation; four of these courses (12 credits) are normally completed while the student is registered in the Division of Basic Studies. However, students whose career goals require them to do so, may substitute introductory courses in the natural sciences (e.g., biology or organic chemistry) for their liberal studies electives during the freshman or sophomore year, and defer these electives until the junior and senior years. The liberal studies electives may include courses in the humanities, social sciences, modern foreign languages, and expressive arts.

All undergraduate students are required by the University to complete four terms of work in physical education. The requirement must be completed within the first four terms unless postponement is granted by the University Academic Records and Instruction Committee. Descriptions of the physical education courses offered will be made available to entering students by the Department of Physical Education and Athletics. For further details, see the *Announcement of General Information.*

During the sophomore year students take four engineering core science courses, selected from offerings in four areas, as outlined on p. 24. Students who are planning to major in chemical engineering as upperclassmen must satisfy special prerequisites (see footnote, p. 24). A wise selection of core courses is of considerable importance to the student's subsequent program of studies and should be made in close cooperation with a faculty adviser.

The Curriculum

Typical programs for the freshman and sophomore years are given as examples. It should be noted that there are many variations, depending on students' individual backgrounds and educational and career plans. Where there are differences, the former course numbers are listed in parentheses next to the new ones.

Freshman Year

Term 1	*Hours*
Mathematics BMA191, Calculus for Engineers	4
Chemistry BCH207 (107), General Chemistry	3

Freshman Engineering Course IBE105 or IBE106	3
Natural or Social Science Elective	3
Liberal Studies Elective	3

Term 2

Mathematics BMA192 or BMA194, Calculus for Engineers	4
Physics BPS112, Physics 1	4
Freshman Engineering Course IBE105 or IBE106 or alternative*	3
Natural or Social Science Elective†	3
Liberal Studies Elective	3

Sophomore Year

Term 3	*Hours*
Mathematics BMA293 or BMA295 (293H), Engineering Mathematics	4
Physics BPS213, Physics II	4
Engineering Core Science Elective	3
Engineering Core Science Elective	3
Liberal Studies Elective	3

Term 4

Mathematics BMA294 or BMA296 (294H), Engineering Mathematics	3
Physics BPS214, Physics III	4
Engineering Core Science Elective	3
Engineering Core Science Elective	3
Liberal Studies Elective	3

* Students interested primarily in bioengineering or bioengineering-premedicine may substitute Biological Science OBA102 plus OBA104 (laboratory) for IBE106 (see p. 30).
† Students who wish to major in chemical engineering and students who are interested primarily in bioengineering-premedicine must take Chemistry BCH208 during the freshman year. Chemical engineering students will select a considerably different program in the sophomore year (see footnote § under Engineering Core Sciences).

Engineering Core Sciences

Four engineering core science courses must be taken during the sophomore year. Each student selects his courses from the four groups listed below, choosing a minimum of one course from three of the four groups. An important consideration in the choice of these courses is that each upperclass Field Program is entitled to specify a particular engineering core science as a prerequisite for enrollment in the junior year.

For convenience the former course numbers are listed in parentheses next to the new course numbers.

Group I	*Hours*
IOA213 (9113), Systems Analysis and Design	3
IOA260 (9160), Introductory Engineering Probability*	3
IOA270 (9170), Basic Engineering Statistics	3
ICS211 (202), Computers and Programming	3

Group II

IEE210 (4210), Introduction to Electrical Systems†	3
ITA262 (6262), Electrical Properties of Materials	3
IPK217 (8117), Contemporary Applied Physics	3

Group III

IAK201 (1001), Introduction to Applied Mechanics	3
IAK221 (1021), Mechanics of Solids‡	3
IAK231 (1031), Dynamics	3
ITB261 (6261), Mechanical Properties of Materials	3

Group IV

BCH287, BCH289 (Chemistry 287, 289), Physical Chemistry	5
BCH288, BCH290 (Chemistry 288, 290), Physical Chemistry	5
BCH357 (Chemistry 357), Organic Chemistry	3
BCH358 (Chemistry 358), Organic Chemistry	3
IMG221 (3631), Thermodynamics	3
IHE111 or IHE110 (5101 or 5111), Mass and Energy Balances§	3

* Required for Industrial Engineering.
† Required for Electrical Engineering or Engineering Physics.
‡ Required for Mechanical and Aerospace Engineering or Civil and Environmental Engineering.
§ Sophomores who wish to major in Chemical Engineering must take Chemistry BCH287–289, Chemistry BCH288–290, and IHE111 or IHE110. Only two of these courses may be counted toward the four engineering core sciences required of all sophomores. Students who take these three courses during the sophomore year may be unable to complete the engineering core sciences requirements that year, and may defer the fourth core science until the junior year.

Aerospace Engineering

See p. 48.

Agricultural Engineering

Riley-Robb Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Agricultural), Master of Science, Doctor of Philosophy.

E. S. Shepardson, director; R. D. Black, J. R. Cooke, R. B. Furry, W. W. Gunkel, D. A. Haith, L. H. Irwin, G. Levine, R. C. Loehr, H. A. Longhouse, R. T. Lorenzen, D. C. Ludington, W. F. Millier, G. E. Rehkugler, N. R. Scott, J. W. Spencer.

Courses of instruction are listed on pp. 65–68.

A joint program administered by the College of Agriculture and Life Sciences and the College of Engineering leads to the degree of Bachelor of Science. Students in this curriculum register in the College of Agriculture and Life Sciences during the first three years but also take courses in the College of Engineering and the College of Arts and Sciences. They register in the fourth and final year for a College Program in the College of Engineering, which grants the degree.

The purpose of this curriculum is to prepare engineers for careers in the many industries and agencies that supply the great variety of products, machines, and services required for commercial agriculture, or that process, handle, and distribute agricultural products. More specialized study is offered in the various graduate degree programs.

Laboratory and Research Facilities

Riley-Robb Hall, on the campus of the College of Agriculture and Life Sciences, provides excellent classroom and laboratory facilities for both teaching and research. Major items of laboratory equipment include electric dynamometers, universal testing machines, fluid flow demonstration and metering equipment, strain measurement instruments, digital recording equipment, an electronic analog computer, torque meters, high speed camera and film analysis equipment, modern farm machines, power units and materials-handling equipment, soil properties and moisture determination apparatus, and complete machine shop facilities.

Laboratory equipment and space in Riley-Robb Hall permit investigation of many aspects of agricultural waste management, including liquid and solid waste handling, treatment and disposal, and odor control. A separate waste treatment laboratory is used for waste management pilot plant studies.

The Department has an extensive research program supported through the Cornell Agricultural Experiment Station. This also serves to provide many students with opportunities for part-time work during the academic year and for summer employment.

The Degree Programs

Bachelor of Science

The program for the underclass years is as follows.

Term 1	*Hours*
BMA191, Calculus for Engineers	4
BCH103, Introduction to Chemistry	3
or	
BCH207 (formerly 107), General Chemistry	3
or	
BCH215 (formerly 115), General Chemistry and Inorganic Qualitative Analysis	4
OAE153, Engineering Drawing	3
OBA101, Biological Science	3
or	
OBA207 (formerly 107), Biology for Nonmajors	3
Liberal Studies Elective	3
Term 2	
BMA192, Calculus for Engineers	4
BPS112, Physics I	4
OAE152, Introduction to Agricultural Engineering Measurements	3
OBA102, Biological Science	3
or	
OBA208 (formerly 108), Biology for Nonmajors	3
Liberal Studies Elective	3
Term 3	
BMA293, Engineering Mathematics	4
BPS213, Physics II	4
IAK201, Introduction to Applied Mechanics	3
Engineering Science	3
Liberal Studies Elective	3
Term 4	
BMA294, Engineering Mathematics	3
BPS214, Physics III	4
Engineering Science	3
Engineering Science	3
Liberal Studies Elective	3

In addition to these courses, all freshmen and sophomores must satisfy the University's requirements in physical education.

The curriculum for terms 5 to 8 consists of:

1. A structured program of at least forty-two credit hours including *(a)* a minimum of thirty hours of engineering courses including at least eleven hours of agricultural engineering courses at the 450 level or higher; and (*b*) a minimum of twelve hours of biological sciences and/or agricultural electives.

2. Additional free elective and other courses designed to provide depth in the student's major areas of interest, as well as to satisfy the requirements for ninety hours of courses in the core curriculum and a total of at least 126 hours (as required by the College of Engineering).

A complete description of the courses in agriculture may be found in the *Announcement of the College of Agriculture and Life Sciences.*

Specialization in agricultural engineering does not require the period of practice before graduation that is required for specialization in some areas of agricultural study. However, appropriate summer work experience is encouraged, and faculty advisers will assist their advisees in obtaining suitable jobs.

To remain in good standing in the agricultural engineering program, a student must attain each term a weighted average of at least 1.7.

Agricultural Engineering Minor (College Program). College Program students interested in the application of engineering to plant and animal systems may elect an agricultural engineering minor which has the following requirements: (1) a minimum of six hours of agricultural engineering courses at the 400 level or above; (2) a minimum of six hours of biological science and/or agriculture courses beyond the introductory biological science sequence; and (3) a minimum of six hours of engineering courses related to the student's interest in agricultural engineering. These courses are selected by the student in consultation with his faculty adviser for the minor.

Master of Engineering (Agricultural)

The degree of Master of Engineering (Agricultural) is available as a curriculum type of professional degree, intended primarily for those students who plan to enter engineering practice and not for those who expect to study for the doctorate. This program consists of courses which are intended to develop the student's background in engineering design as well as to strengthen his fundamental engineering base. Six hours of the required thirty hours consist of engineering design experience involving individual effort and a formal report. Admission to the M.Eng. (Agricultural) program is open to persons who have been granted Bachelor's degrees or the equivalent and who have sufficient training to indicate that they can profitably study the advanced courses offered in the program. A student can choose to concentrate his studies in one of the subareas of agricultural engineering or take a broad program without specialization. The subareas are: *(a)* power and machinery, *(b)* soils and water engineering, *(c)* agricultural structures and associated systems, *(d)* electric power and processing, and *(e)* agricultural waste management.

Engineering electives are chosen from among subject areas relevant to agricultural engineering, such as thermal engineering; mechanical design and analysis; theoretical and applied mechanics; structural engineering; hydraulics; sanitary engineering; soil engineering; and waste management.

Master of Science and Doctor of Philosophy

Flexible programs leading to the Ph.D. degree are offered in the following areas of specialization: agricultural engineering, agricultural structures, power and machinery, soil and water engineering, electric power and processing, and agricultural waste management. Two minor subjects, at least one of which must be in an engineering, agricultural, or basic science subject outside the Field, are also selected. Candidates for the M.S. degree take agricultural engineering as their major subject and select one minor from outside the Field.

A broad and active research program, supported by the Cornell Agricultural Experiment Station, gives the graduate student an opportunity to select a challenging research project for his thesis. Assistantships and traineeships are available, and provide annual stipends comparable to those offered at other land grant institutions.

More detailed information, along with application forms and other descriptive information pertinent to M.S. and Ph.D. programs in this Field, may be obtained by writing to the Office of the Graduate Field Representative, Riley-Robb Hall.

Applied and Engineering Physics

Clark Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Engineering Physics), Master of Science, Doctor of Philosophy.

J. Silcox, director; P. L. Hartman, associate director; B. W. Batterman, R. A. Buhrman, K. B. Cady, D. D. Clark, R. K. Clayton, T. A. Cool, D. R. Corson, H. H. Fleischmann, V. O. Kostroun, J. A. Krumhansl, A. Kuckes, B. R. Kusse, A. Lewis, R. L. Liboff, R. V. Lovelace, M. S. Nelkin, E. L. Resler, Jr., T. N. Rhodin, M. M. Salpeter, B. M. Siegel, R. N. Sudan, W. W. Webb, G. J. Wolga.

Courses of instruction are listed on pp. 68–72.

The solution of many significant problems in engineering and applied science requires a thorough knowledge of physics and applied mathematics, and the ability to apply this knowledge effectively. The degree programs of the School of Applied and Engineering Physics are designed to provide education in the basic sciences at an intellectually challenging level and to prepare the student for a wide range of possible specialization in later professional development. These programs are particularly suitable for students who are willing to defer the early study of specific applications in order to have a wider choice of problems on which they can later work with competence and sophistication.

Research and Laboratory Facilities

The School of Applied and Engineering Physics is centered in Clark Hall, which houses the University's physical sciences library; offices of the Materials Science Center and of the Program on Science, Technology, and Society; research laboratories and supporting services in solid state physics and materials science; and a computer terminal. Facilities of other University laboratories and centers are also available for research in applied and engineering physics; these include the Center for Radiophysics and Space Research, the Ward Laboratory of Nuclear Engineering, the Laboratory of Plasma Studies, and facilities of the Division of Biological Sciences and of other schools and departments in the College of Engineering.

The Degree Programs

Bachelor of Science

The Field Program in Engineering Physics is designed to develop proficiency in physics and applied mathematics with emphasis on those areas of greatest applicability to engineering and to other sciences. Its distinguishing feature is a focus on concepts of broad applicability presented in an intellectually demanding and challenging context. For the able student, it provides an opportunity to develop a general ability to solve difficult problems and to acquire experience in making specific applications. The flexibility of the program allows the student to choose areas of concentration within and outside of physics during the undergraduate years. Most students go on to graduate study in a wide variety of fields, and they find that the strength and flexibility of their undergraduate preparation makes them desirable candidates for admission to many different graduate and professional programs.

It is difficult to predict which particular areas of engineering or applied science will appear most exciting and offer the best career opportunities when a current group of freshmen enters the job market. Certain general trends are clear, however. As more difficult questions are asked in a given field, there is greater need to go back to fundamental knowledge in order to find answers. Particular techniques of application become rapidly obsolete, but the underlying scientific base changes much more slowly. Also, subject areas become more specialized at advanced levels; many subjects that are highly exciting at the graduate level have no direct undergraduate counterparts or are better prepared for by study in basic science and mathematics than by specialized undergraduate work. Conversely, excitement in the study of physics is increasingly the result of its applications in other scientific areas and in engineering.

Many undergraduates who pursue a major in engineering physics go on to graduate work in such fields as astrophysics, atmospheric sciences, biophysics, energy conversion, environmental science, geophysics, materials science and engineering, nuclear engineering, nuclear physics, oceanography, plasma physics, quantum optics, and solid state electronics. Since a proper preparation for many of these areas of study depends upon an appropriate choice of undergraduate electives, each student should discuss his program with an engineering physics faculty member as early as possible during the undergraduate years. Some currently active areas of study and the names of professors who have special interest in these areas are: *Biophysics,* A. Lewis and W. Webb; *geophysics,* A. Kuckes; *materials science,* J. Silcox; *nuclear engineering,* D. Clark and K. B. Cady; *lasers and quantum electronics,* G. Wolga; *plasma physics,* H. Fleischmann and B. Kusse.

Another alternative for students who specialize in engineering physics as undergraduates is entry into a professional Master of Engineering program in engineering physics, nuclear engineering, or aerospace engineering. Further study in other professional fields for which a background in applied science is less directly applicable is also a possibility. Some baccalaureate graduates go directly to industrial positions that often entail on-the-job or advanced training programs. As in all the engineering fields at Cornell, the four-year Bachelor of Science degree in engineering physics is not a professional engineering degree.

The first two years of the undergraduate program are administered by the Division of Basic Studies (see pp. 23–24). Students who are planning to enter the Field Program in Engineering Physics are encouraged to register in Honors sections of physics and mathematics during these two years. Those who have advanced standing in mathematics when they matriculate in the College are advised of the possibility of taking Physics BPS112 in the fall term of the freshman year and Mathematics BMA421 in the spring term of the sophomore year. Of the core engineering sciences studied in the first two years, either IEE210, Introduction to Electrical Systems, or a course in thermodynamcs (IMG211 or Physical Chemistry BCH287) is required. Whichever of these subjects is not studied during the first two years must be taken in the junior year through an appropriate course as discussed below. The course IPK217, Contemporary Topics in Applied Physics, is strongly recommended for the spring semester of the sophomore year.

The following curriculum, or its equivalent, constitutes the upperclass Field Program.

Term 5	*Hours*
BMA421, Applicable Mathematics	4
IPA355, Intermediate Electromagnetism	4
IPA333, Mechanics of Particles	4
Engineering Science*	3 or 4
Liberal Studies Elective	3 or 4

Term 6

BMA422, Applicable Mathematics	4
IPA456, Intermediate Electrodynamics	4
IPG461, Introductory Quantum Mechanics	4
Free Elective	3 or 4
Liberal Studies Elective	3 or 4

Term 7

BMA423, Applicable Mathematics	4
IPG323, Statistical Physics	4
BPS410, Advanced Experimental Physics	4
Technical Elective	3 or 4
Liberal Studies Elective	3 or 4

Term 8

IPA434, Continuum Physics	4
Applications of Quantum Mechanics†	3 or 4
Technical Elective	3 or 4
Free Elective	3 or 4
Liberal Studies Elective	3 or 4

* For those students who have taken IEE210 and a thermodynamics course in the sophomore year, this becomes a free elective. For those who have taken thermodynamics only, Physics BPS360 is suggested to meet the electric circuits requirement. For those who have taken IEE210 only, a course in thermodynamics is required.

† A choice of the following courses may be made: BPS454, Introductory Solid State Physics; BPS444, Nuclear and High-Energy Particle Physics; IPC609, Low-Energy Nuclear Physics (fall term); IPD401, Physics of Atomic and Molecular Processes (fall term); IEE731, Quantum Electronics I (fall term).

Considerable flexibility is possible in the scheduling of these courses. For example, Physics BPS410 may be taken in term 7 or in term 8. Quantum mechanics can be studied in term 6 as IPG461 or in term 7 as Physics BPS443. The course in applications of quantum mechanics can be taken whenever the appropriate prerequisite has been met. If scheduling conflicts arise, the School may allow substitutions of courses nearly equivalent to the listed required courses: Physics BPS325–326 and IEE313–314 are similar to IPA355 and IPA456; Physics BPS318 (offered in the spring) and IAC670 are similar to IPA333; and one of a number of advanced courses in fluid mechanics or elasticity are similar to IEP434.

Free and technical electives need not be all formal course work; qualified students may undertake informal study under the direction of a member of the faculty. This may include research projects during the senior year in areas in which faculty members are active. These areas include electron microscopy and diffraction, quantum electronics, solid state and surface physics, atomic physics, geophysics, biophysics, nuclear structure physics, nuclear engineering, and plasma physics.

The engineering physics student is expected to pass every course for which he is registered, to attain each term a grade-point average of at least 2.3, and to demonstrate aptitude and competence in the basic subject matter of the curriculum.

Interdisciplinary Study. Through a judicious choice of electives in the first two years, a student who plans to enroll in engineering physics can develop a coherent supplementary program in an area outside of physics. This can be important in preparing for graduate work in many interdisciplinary fields. Three typical examples are the following.

(1) A student interested in biophysics may choose the introductory biology courses OBA101–103 and OBA102–104 as his natural science electives in the freshman year. (It should be noted, however, that a student with good preparation in high school biology may qualify, by taking the necessary placement examinations in the fall, for OBA109, which offers introductory biology in one term.) A good selection of electives for the sophomore year would be IPF306, The Physics of Life, taken along with the organic chemistry sequence BCH253 in the fall term and either BCH301 (a four-hour course) or BCH251 (a two-hour course) in the spring term. During the junior year this student could elect physical chemistry (BCH389–390). He could meet the senior-year requirement for a course in applications of quantum mechanics by taking Physics BPS454, or Applied and Engineering Physics IPD401, or Chemistry BCH794, or Chemistry BCH798. Finally, technical electives that would be appropriate for this student include the biology courses OBD431 and OBD433; OBB410 and OBB411; OBC320; OBI280; OBA405; OBC425; IPF601; IPF603; OBB313; and OBI386.

(2) A student interested in geophysics may choose geological sciences courses IGE101–102 or else IGE101 and Chemistry BCH208 as his natural science electives in the freshman year. In the sophomore year an appropriate choice of engineering sciences would be IEE210, ITA261, IMG221, and IPK217. In the junior year the geological sciences sequence IGE355–356 or IGE325 and IGE376 would be appropriate electives. Senior-year electives could include IGE485 and IGE388. The applications of quantum mechanics requirement would be met best with Physics BPS454.

(3) A student interested in nuclear engineering or nuclear science would be advised to select IEE210, IMG221, and IPK217 as three of his sophomore engineering core sciences. Appropriate electives in later terms would be IPC201 in term 5, IPC609 as the required course in applications of quantum mechanics in term 7, and IPC612 as a technical elective in term 7.

Similar programs may be set up in other areas;

examples are available at the office of the School of Applied and Engineering Physics. Students interested in this kind of interdisciplinary study are urged to develop programs that meet their specific objectives at the earliest possible time. They are advised to consult with one of the professors listed in this section under particular areas of interest or with the associate director of the School, P. L. Hartman.

The College Program. Students who elect to develop a College Program (see pp. 36–38) may choose a major from an area of applied physics. A College Program major in nuclear engineering, for example, might include the Applied and Engineering Physics courses IPC201 and IPC303, plus two of the four courses IPC612, IPC651, IPC633, and IPC609. Also available is a College Program in Energy Conversion, a synthesis of nuclear, thermal, and electrical engineering studies. This program is described on p. 37. Consultation with faculty members in the general area of the desired major must be made before embarking on a College Program.

Master of Engineering (Engineering Physics)

The primary objective of the fifth year of study in engineering physics is to provide an opportunity for advanced study at the professional level; students who earn the M.Eng. (Engineering Physics) degree may move into development or research programs in applied physics in industrial or governmental institutions. The program may also serve as a preparation for more advanced graduate work in applied physics, or as exploratory study for the student interested in starting graduate work but not ready to make a commitment to a specific field. Finally, it provides an opportunity to satisfy prerequisite course work in certain new areas of graduate study which involve a combination of engineering or applied physics with another professional but nontechnical discipline.

General requirements for the M.Eng. degree, given on p. 11, permit considerable flexibility in the course program, and Engineering Physics students plan individual curricula in consultation with the program chairman. Specific requirements for the M.Eng. (Engineering Physics) degree are the following:

1. The required thirty credit hours must include a minimum of six in a graduate-level course sequence. The program must also include a graduate-level course in quantum mechanics and a fourth-year or graduate-level course in statistical mechanics, or their equivalents, unless such courses have been taken as part of the undergraduate program. In addition, the student must attend a sequence of approximately fifteen scheduled University seminars or colloquia chosen in consultation with the chairman of the program.

2. The project requirement may be satisfied by an informal study or project, experimental or analytical, which requires individual effort and is completed with a formal report. This carries at least six hours of credit. It is usually completed by the end of the second semester but permission to continue through the summer may be obtained. If the project is experimental, one course in mathematics or applied mathematics at the graduate level is required; if the project is analytical, one term in experimental laboratory physics at the graduate level or its equivalent must be taken. The study or project is chosen in consultation with the chairman of the program and is carried out under the personal direction of an appropriate member of the engineering or science faculty.

Inquiries about the study program, available facilities, admission requirements, or financial aid should be addressed to the Program Chairman, Master of Engineering (Engineering Physics), Clark Hall.

Master of Engineering (Nuclear)

This program is described under the Nuclear Science and Engineering section of this *Announcement* (see p. 54).

Master of Science and Doctor of Philosophy

The graduate program in the Field of Applied Physics provides a means for students with undergraduate training in physics to branch out into applied science while continuing the study of physics and for students with backgrounds in engineering or another science to extend their knowledge of physical science principles and techniques. A student may choose for specialization and thesis research any subject that involves the application of principles of physics and mathematics. The formal course programs leading to the M.S. and Ph.D. degrees contain a core of physics and mathematics courses, but individual programs of study are designed to meet the needs and interests of each student. Programs involving several academic disciplines and topics that are undergoing transition from fundamental physics to applied physics are readily accommodated.

Current areas of advanced study and research include: applied theoretical physics, biophysics, chemical physics, physics of fluids, nuclear and reactor physics, optics, plasma physics, radiation and matter, solid state physics and materials sciences, space physics, and surface physics. Specific research projects in which graduate students in applied physics are currently participating include studies of coherence of light generated by lasers, superconductivity in high magnetic fields, phase transformations at high pressures, high resolution electron optics, studies of quantum electronics using infra-red spectroscopy, observations of critical phenomena in fluids using homodyne spectroscopy, experimental and theoretical studies on the confinement and heating of thermonuclear plasmas, observations of the atomic structure of crystal surfaces by field ion microscopy and low energy electron diffraction, analysis of nuclear structure by analysis of the decay of short-lived radio isotopes formed in a pulsed nuclear reactor, theoretical studies of plasma instabilities, molecular dynamics in fluids, the statistical physics of phase transitions in quantum fluids, and experimental studies of atomic collisions and X-ray physics.

Details of the program, requirements for admission, and areas of advanced study are given in the *Announcement of the Graduate School.* A special *Announcement, Graduate Study in Engineering and Applied Science* includes a section on Applied Physics. Further information may be obtained from the Field Representative, Applied Physics, Clark Hall.

Bioengineering

Bioengineering at Cornell is diverse, with specific bioengineering and premedical studies offered in the Division of Basic Studies and most of the upperclass engineering Fields. Normally, students interested in bioengineering complete their engineering and basic science prerequisites, including biology and organic chemistry, during their freshman and sophomore years. In the junior and senior years, students pursue bioengineering options within their chosen engineering Fields by choosing their electives to support their special goals without detracting from the essential engineering foundation provided by a Field Program.

When pursuing a biological emphasis in an organized degree-granting undergraduate Field, students receive outstanding preparation in the particular field of engineering, plus the background to apply this knowledge in diverse areas of ecology, biology, or medicine. By careful selection of electives a student will complete the senior year with the educational option of: (1) further graduate study in biology, ecology, or medicine, or (2) additional study in the engineering Field. The wisdom of retaining two options has proved itself; the faculty of the College is strongly committed to the idea that students be adequately prepared engineers with a variety of options upon graduation.

A few students have sufficient experience to decide upon an area of specialization without retaining other options. For these students an individualized curriculum can be designed within the College Program (see p. 36). This Program has been used effectively by students whose principal educational aim was matriculation in a medical college and by a few bioengineering students who wished to combine different engineering emphases. Since there is no set curriculum in the College Program, the key to formulating a viable bioengineering course of study lies in finding appropriate faculty advisers who are knowledgeable in the major and minor areas of concentration. The faculty resources of the College, and other units of the University, have proved excellent in meeting this need.

During the first two years, all students in the College of Engineering are enrolled in the Division of Basic Studies to pursue a program combining specified course work with electives appropriate to their field of interest. A student interested in upperclass work in bioengineering or premedicine has the opportunity to modify the curriculum so that he can accomplish all of the basic prerequisites for this kind of specialty by the end of the sophomore year.

The following program is suggested as a guide; it is understood that each bioengineering student will discuss his plans carefully with his faculty adviser before making decisions regarding his course of study. For example, students who receive advanced placement credit will need to consult with their advisers to determine suitable schedules.

Term 1	*Hours*
Mathematics BMA191, Calculus for Engineers	4
Chemistry BCH207, General Chemistry	3
Engineering IBE105, Elements of Engineering Communication	3
Biological Sciences OBA101 and OBA103, or OBA105, or OBA109*	4
Liberal Studies Elective	3
Term 2	
Mathematics BMA192, Calculus for Engineers	4
Chemistry BCH208, General Chemistry	3
Biological Sciences OBA102 and OBA104, or OBA106, or OBA110*	4
Physics BPS112, Physics I: Mechanics and Heat	4
Liberal Studies Elective	3
Term 3	
Mathematics BMA293, Engineering Mathematics	4
Physics BPS213, Physics II: Electricity and Magnetism	4
Engineering Core Science	3
Chemistry BCH253, Elementary Organic Chemistry	4
or	
Chemistry BCH357, Introductory Organic Chemistry†	3
Liberal Studies Elective	3
Term 4	
Mathematics BMA214, Engineering Mathematics	3
Physics BPS214, Physics III: Optics, Waves, and Particles	3
Engineering Core Science	3
Chemistry BCH251, Elementary Organic Laboratory	2
or	

Chemistry BCH358, Introductory Organic Chemistry† 3
Liberal Studies Elective 3

**Either* Biological Sciences OBA101 and OBA103, OBA102 and OBA104, or OBA105 and OBA106 are recommended for biology majors and will serve satisfactorily for premed students; alternatively, the nonmajor courses OBA109 and OBA110 could be chosen. Students who are free to attend summer session may wish to take the biology sequence, in whole or in part, during the summer, as this eases the work load during the academic year.
† Students are encouraged to discuss with their advisers whether chemistry is appropriate to their interests and which chemistry courses are best suited. (Chemical Engineering majors would choose Chemistry BCH287, BCH289, BCH288, BCH290, Physical Chemistry.)

Using this curriculum as a basic guide, students should consult their advisers regarding possible variations that might stress particular needs or unusual situations. Current copies of *Medical School Admissions Requirements,* which lists appropriate courses, are available in the Advising and Counseling Center, along with catalogs from many universities that offer graduate bioengineering programs.

The many course programs available to bioengineering students in upperclass engineering Fields cannot be described in this *Announcement* because of space limitations. Detailed descriptions of these course offerings and suggested curricula are, however, essential for bioengineering students who are seeking to make an intelligent decision regarding a Field of study for the junior and senior years. Before preregistering for the sophomore year, bioengineering students should obtain from the Engineering Advising and Counseling Center, a copy of *Bioengineering at Cornell,* which provides the information necessary for putting the decision-making process in perspective.

Chemical Engineering

Olin Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Chemical), Master of Science, Doctor of Philosophy.

K. B. Bischoff, director; J. C. Smith, associate director; J. L. Anderson, G. G. Cocks, R. K. Finn, P. Harriott, J. E. Hedrick, F. Rodriguez, G. F. Scheele, J. F. Stevenson, R. G. Thorpe, R. L. Von Berg, H. F. Wiegandt, C. C. Winding, R. York.

Courses of instruction are listed on pp. 73–77.

Chemical engineering involves the application of the principles of the physical sciences and mathematics and of engineering judgment to fields in which matter is treated to effect a change in state, energy content, or chemical composition. Many chemical engineers are employed in the process industries. In these industries, raw materials are converted to useful products such as industrial chemicals, petroleum products, metals, rubbers, plastics, synthetic fibers, foods, paints, and paper. Because of their knowledge of chemistry, chemical engineers are also prepared to serve in related fields such as biochemical and biomedical engineering, nonmetallic materials, waste disposal, and pollution abatement.

An integrated program in chemical engineering leads to a Bachelor of Science degree at the end of four years and to a Master of Engineering degree in one additional year. The curriculum applies the latest developments in the fields of chemistry, mathematics, physics, and the engineering sciences to chemical engineering concepts and provides enough flexibility so that students may prepare themselves for the broad application of these concepts to many engineering problems. A four-year sequence of liberal studies electives provides an opportunity to attain a background in the social sciences, economics, or other nontechnical subjects. Free electives in the upperclass years permit the choice of additional courses in such fields. Free and technical electives may be used to broaden the student's preparation in the sciences and engineering or to study specialties in more depth. The School of Chemical Engineering offers special programs in biological engineering, polymeric materials, and chemical microscopy. Students may also use their electives to attain greater proficiency in fields such as chemistry, mathematics, biology, environmental systems engineering, water resources, computer science, or nuclear engineering.

Laboratory and Research Facilities

All Cornell programs in chemical engineering, both undergraduate and graduate, are given in Olin Hall of Chemical Engineering. This modern and well-equipped building, with over 100,000 square feet of floor space, provides lecture and recitation rooms as well as laboratories for instruction and research. The main laboratory extends through three floors and contains pilot-plant equipment for undergraduate projects and research as well as space for research apparatus for graduate students. Shops, storage, and service facilities are adjacent to this laboratory.

In addition, a large portion of the building is devoted to small-unit laboratories containing furniture and equipment suitable for the chemical and bench-scale projects and research carried out by both undergraduate and graduate students. Specialized laboratories are also available. The Geer Laboratory for Rubber and Plastics has facilities for making, processing, and testing all types of polymeric materials. The biochemical engineering laboratory contains equipment for fermentation and other biochemical processes; the process control area is equipped with control instruments, recorders, and computers.

The Degree Programs

Bachelor of Science

The Field Program in Chemical Engineering offers a coordinated sequence of chemical engineering courses beginning in the sophomore year and extending through the fourth year.

Course programs for terms 1 through 4, administered by the Division of Basic Studies, are described on pp. 23–24. While enrolled in the Division of Basic Studies, the student planning to enter the professional chemical engineering program registers for Chemistry BCH287–288, Chemistry BCH289–290, and Chemical Engineering IHE110 (formerly 5111) or IHE111 (formerly 5101) during the sophomore year.

The program for the upperclass years is as follows.

Term 5	*Hours*
Chemistry BCH357, Organic Chemistry	3
IHE311, Equilibria and Staged Operations	3
IHE321, Materials*	5
Elective†	3
Liberal Studies Elective	3
Term 6	
Chemistry BCH358, Organic Chemistry	3
Chemistry BCH251, Organic Chemistry Laboratory	2
IHE430, Introduction to Rate Processes	3
IHE312, Chemical Engineering Thermodynamics	3
Elective†	3
Liberal Studies Elective	3
Term 7	
IHE431, Analysis of Separation Processes	3
IHE432, Chemical Engineering Laboratory	3
IHE461, Chemical Process Evaluation	4
Elective†	3
Liberal Studies Elective	3
Term 8	
IHE410, Reaction Kinetics and Reactor Design	3
IHE462, Chemical Process Synthesis*	4
Electives†	6
Liberal Studies Elective	3
IHE101, Nonresident Lectures	0

* Students who have an approved plan for concentration in a minor topical area and who require more elective courses than the number scheduled to accomplish their goals may substitute additional electives for IHE321, Materials (provided that ITA261, Mechanical Properties of Materials, has been chosen as an engineering core science during the sophomore year) and/or IHE462, Chemical Process Synthesis. This option could be of interest to students planning concentrations in such areas as biological engineering, environmental studies, advanced chemistry, and systems and operations research.

† The electives must include the postponed engineering core science course (see the section on Basic Studies).

The College Program. Students pursuing a College Program, described on p. 36, may elect a major or a minor in chemical engineering. These majors and minors require a sequence of chemical engineering courses in the third and fourth years, plus the proper prerequisites, as specified by the student's adviser and the College Program Committee.

Master of Engineering (Chemical), Master of Science, and Doctor of Philosophy

A student holding a baccalaureate or equivalent degree in chemical engineering from a college of recognized standing is eligible to pursue advanced work leading to a professional degree, Master of Engineering (Chemical), or to the general degrees, M.S. or Ph.D., with majors in chemical engineering.

The professional master's degree, M.Eng. (Chemical), is awarded at the end of one year of study with successful completion of thirty credit hours of required and electives courses in technical fields including engineering, mathematics, chemistry, physics, and biology. Courses emphasize design and optimization based on the economic factors that affect process, equipment, and plant design aternatives. No thesis is required, but a design project is involved in the required courses. Further information may be obtained from the Director of Chemical Engineering, Olin Hall.

The M.S. and Ph.D. degrees are administered by the Graduate School and require work in both major and minor fields of study, as well as the completion of a thesis involving individual experimental research or analytical investigations. A student interested in these degrees should consult the *Announcement of the Graduate School* and an *Announcement* titled *Graduate Study in Engineering and Applied Science* (see p. 4). Prospective candidates may also communicate with the Graduate Field Representative, School of Chemical Engineering, Olin Hall.

Civil and Environmental Engineering

Hollister Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Civil), Master of Science, Doctor of Philosophy.

W. R. Lynn, director; G. B. Lyon, assistant director; V. C. Behn, D. J. Belcher, P. L. Bereano, J. J. Bisogni, W. H. Brutsaert, L. B.

Dworsky, G. P. Fisher, R. H. Gallagher, C. D. Gates, P. Gergely, D. A. Haith, J. N. Kay, A. Wm. Lawrence, T. Liang, J. A. Liggett, R. C. Loehr, D. P. Loucks, W. McGuire, A. J. McNair, A. H. Meyburg, A. H. Nilson, T. Peköz, D. A. Sangrey, R. E. Schuler, R. G. Sexsmith, C. Shoemaker, F. O. Slate, S. Stidham, Jr., H. M. Taylor, 3d, R. N. White, G. Winter.

Courses of instruction are listed on pp. 77–89.

Civil and environmental engineering deals primarily with the large fixed works, systems, and facilities that are basic to community living, industry, and commerce and vital to man's well-being. The planning, design, construction, and operation of transportation systems, bridges, buildings, water and sewage treatment facilities, dams, and other major artifacts of society are civil and environmental engineering activities. Civil and environmental engineers are major contributors to the solution of problems of urbanization, city planning, and environmental quality control. A burgeoning national population and the desire of people to cluster in city complexes require a great increase in the number of well-prepared engineers who can meet the basic needs of society with efficiency, economy, and safety.

The wide range of subjects which are the concerns of civil and environmental engineers are generally grouped into a number of sub-fields and specializations. At Cornell, there are two subject departments in the School of Civil and Environmental Engineering—Structural Engineering (see p. 34) and Environmental Engineering (see p. 35)—and a Program in Measurement and Remote Sensing (see p. 35). Within the department of Environmental Engineering, there are three major areas: environmental protection and management, fluid mechanics and hydrology, and public systems planning and analysis.

These units provide courses for graduate study leading to advanced degrees and also those courses necessary to support the undergraduate curriculum in civil and environmental engineering. The specific aims, objectives, and programs of each of these units are described on the pages listed above.

The Degree Programs

The undergraduate field curriculum in civil and environmental engineering leads to the degree of Bachelor of Science. It provides a thorough foundation in the basic sciences, applied sciences, and mathematics which are fundamental to the profession. It also includes an introduction to the major areas of modern civil and environmental engineering technology and substantial opportunity for liberal study.

Most students go on to graduate study after completion of the baccalaureate. The three main paths of advanced work at Cornell are:

1. Graduate study in the Field of Civil and Environmental Engineering leading to the degree of Master of Engineering (Civil). This is the first degree with a civil engineering designation. It is obtained upon completion of a curricular program of thirty credit hours of advanced study, including an extensive design project. The M.Eng. (Civil) program is designed primarily for students who intend to enter the professional practice of engineering, and the degree represents attainment of an educational level considered essential for modern practice.

2. Graduate study leading to the degrees Master of Science and Doctor of Philosophy. These degrees are intended primarily for students who plan careers in research, development, or teaching in an area of civil and environmental engineering.

3. Advanced study in a related technical field such as applied mechanics, aerospace engineering, or urban planning, or in a nontechnical field requiring an engineering background, such as law or business administration.

Bachelor of Science

The first four terms are described on p. 23 of this *Announcement.* The Division of Basic Studies program specifies that two engineering core science courses be taken in each term of the sophomore year. Mechanics of Solids IAK221, is required for entry into the Civil and Environmental Engineering Field Program. It is recommended, but not required, that students planning to enter this Field take IOA260, Introductory Engineering Probability, and either IAK231, Dynamics, or ITA261, Mechanical Properties of Materials, as two of their other sophomore engineering core science courses.

The following recommended sequence of courses is intended to provide an introduction to the several diverse areas within the Field of Civil and Environmental Engineering and to permit more detailed study in at least one area. Students with a well-defined special interest may choose to depart from this sequence. In such cases, a special program should be developed by the student in consultation with a faculty adviser of his choice within the Field, preferably prior to the fifth semester, and submitted to the Field Curriculum Committee for approval. It is advisable for a student to submit an application for a special program as early as the first term of his sophomore year.

Term 5	*Hours*
IAK231, Dynamics*	3
IIC301, Fluid Mechanics	3
IIG301, Structural Engineering I	4
IOA260, Introductory Engineering Probability*	3
Liberal Studies Elective	3
Term 6	
ITA261, Mechanical Properties of Materials*	3
IIE301, Environmental Quality Engineering	3

IID301, Soil Mechanics	3
IIF303, Engineering Economics and Systems Analysis	3
Liberal Studies Elective	3
Term 7	
Civil and Environmental Engineering Electives (2)†	6
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3
Term 8	
Civil and Environmental Engineering Electives (2)†	6
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3

* Satisfactory completion of these engineering core science courses in the Division of Basic Studies increases the number of technical electives accordingly.
† There are distribution requirements for the four civil and environmental engineering electives. The student may obtain information on these requirements from his faculty adviser.

The College Program. As an alternative to the Field Program, a student with a strong interest in an interdisciplinary specialized program may wish to consider the College Program (see p. 36). Where this involves one of the areas of civil and environmental engineering, either as a major or minor subject, the various department faculty members are prepared to advise and assist the student upon request. Examples of College Programs are those combining study in structural engineering and architecture, transportation engineering and urban planning, environmental systems engineering and operations research, sanitary engineering and oceanography, and public systems planning and analysis (see p. 35).

Master of Engineering (Civil)

The Master of Engineering (Civil) degree is designed to prepare a student for professional practice in civil and environmental engineering. General requirements for the program, in addition to those stated on p. 11, include four required courses: two in professional engineering practice, IIK520 and IIK521; and two in design, IIK510 and IIK511 or the equivalent. The second course in design requires the completion of a project involving synthesis, analysis, decision making, and application of engineering judgment. It will be offered as an intensive, full-day, three-week course during the winter intersession.

The remainder of a student's program of studies is designed individually in consultation with an academic adviser and then submitted to the School's Professional Degree Committee for approval. The objectives in course planning are to provide breadth in the fundamentals of civil and environmental engineering, and specialization in one area with some concentration in a related area. Most students will have achieved the necessary breadth during their undergraduate years. Some, however, may require additional course work in the graduate program to fulfill the breadth requirement. Students in the School of Civil and Environmental Engineering may avail themselves of a number of graduate course offerings in fields related to their major interest but outside of the School.

Further information on this program may be obtained from the Director, School of Civil and Environmental Engineering, Hollister Hall.

Master of Science and Doctor of Philosophy

The requirements for the degrees of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School*. These are degrees oriented toward research and require submission of a thesis.

In the Field of Civil and Environmental Engineering, a number of special areas of concentration are available as either major or minor subjects. These concentrations are identified with the departments of Structural Engineering and Environmental Engineering, and with the Program in Measurement and Remote Sensing, which provide related graduate instruction.

A number of fellowships and assistantships are available to graduate students in civil and environmental engineering. Prospective graduate students should consult the *Announcement of the Graduate School* and a special *Announcement, Graduate Study in Engineering and Applied Science* (see p. 4). Further information may be obtained by writing to the Graduate Field Representative, Civil and Environmental Engineering, Hollister Hall.

Department of Structural Engineering

R. H. Gallagher, chairman; P. Gergely, J. N. Kay, W. McGuire, A. H. Nilson, T. Peköz, D. A. Sangrey, R. G. Sexsmith, F. O. Slate, R. N. White, G. Winter.

Structural engineering comprises the analysis and design of structures of all types, those traditionally identified with civil engineering (e.g., buildings, bridges, watertanks, dams, and foundations) as well as those connected with other branches of engineering (e.g., aerospace structures, pressure vessels, and nuclear engineering structures). Soil mechanics and foundation engineering are concerned with the measurement of soil and rock properties and their use in the design process. The Department of Structural Engineering is responsible for undergraduate and graduate instruction and for research in all these areas. In addition, instruction and research in civil engineering structural materials (e.g., concretes, asphalts, structural metals, and soils) are the Department's responsibility.

Instruction, both undergraduate and graduate, emphasizes fundamental understanding of structural behavior and modern methods of design and analysis, many of them computer-oriented. A large volume of research, sponsored by governmental agencies and industry, is carried out in four large and fully equipped laboratories: a structural laboratory for full-scale testing, a models laboratory, a versatile cement and concrete laboratory, and a soil mechanics laboratory with a wide variety of both standard and specialized equipment.

Department of Environmental Engineering

C. D. Gates, acting chairman; V. C. Behn, P. L. Bereano, J. J. Bisogni, W. H. Brutsaert, L. B. Dworsky, G. P. Fisher, D. A. Haith, A. Wm. Lawrence, J. A. Liggett, R. C. Loehr, D. P. Loucks, A. H. Meyburg, R. E. Schuler, C. Shoemaker, S. Stidham, Jr., H. M. Taylor, 3d.

Environmental engineering is concerned with a large number of interrelated problem areas: the physical, biological, chemical, and social phenomena which characterize the environment; design and development of technological innovations to protect and improve the quality of the environment; and planning, analysis, and assessment of technical and economic alternatives for control of environmental quality. Because of the broad scope of environmental engineering and in order to identify special instructional and research capabilities, the Department of Environmental Engineering is concerned with three areas: *Environmental Protection and Management, Fluid Mechanics and Hydrology, and Public Systems Planning and Analysis.* Faculty members in the Department are frequently active in more than one of these areas.

Environmental Protection and Management

Environmental protection and management is concerned with the phenomena, concepts, methods, and technology essential to maintaining the natural environmental quality at levels beneficial to man. This subject area focuses on the protection and management of air, land, and water resources, on water residuals management, and on environmental quality control. Instruction and research concentrate, first, on the pertinent biological, chemical, physical, and engineering principles and phenomena, and, second, on the use of this knowledge in the planning, design, and management of the processes, systems, facilities, and policies needed to achieve societal environmental quality objectives.

The environmental engineering facilities are housed in approximately 6,300 square feet of laboratory space and controlled-temperature rooms, including water microbiology and water chemistry laboratories, as well as rooms specially equipped for bench and pilot-level unit process studies.

Fluid Mechanics and Hydrology

The proper application of the principles of fluid mechanics, hydraulics, and hydrology is essential to the solution of environmental engineering problems involving the wet earth and the atmosphere. These problems involve the flow of water over and through natural soil and rock, circulation in lakes, dissipation of air-borne materials in the atmosphere, and beneficial utilization of precipitation.

The hydraulics laboratory is equipped for demonstrations in wave mechanics and rotating flows and for a variety of conventional experiments.

Public Systems Planning and Analysis

Public systems planning and analysis involves the application of systems engineering, economic and political theory, and environmental law to public sector problems including environmental quality management, the planning and operation of transportation systems, water resource development, waste residuals management, public health services, and other urban and regional planning problems. It is concerned with the development of improved methods for defining and evaluating alternatives for allocating resources and enhancing the quality of information upon which public investment decisions are made. Current emphasis is placed on transportation systems; air, water, and other natural resource systems; project management; residuals-environmental quality management; and public health, medical, and public services systems.

Graduate students interested in Public Systems Planning and Analysis may major in either Environmental Systems or Transportation (at either the M.S. or Ph.D. level) or in Water Resource Systems (at the Ph.D. level only).

Program in Measurement and Remote Sensing

D. J. Belcher, T. Liang, A. J. McNair.

The design and construction of civil and environmental engineering works requires detailed consideration of present and potential uses of the earth's surface and resources. The Program in Measurement and Remote Sensing is concerned with the sensing, measurement, and evaluation of these related uses.

The techniques of the interpretation of aerial photographs and other remote sensing images, coupled with ground observations, are used to establish the overall nature of the environment, define problems, and aid in their solution. Earth measurement involves surveying, geodesy, photogrammetry, and the related computing and data presentation methods.

The versatile laboratories for both instruction and research in these areas are well equipped with several modern stereoplotters and representative geodetic instruments. The Program maintains a large collection of aerial photographs and images from all over the world which are used in photogrammetric and aerial photographic studies.

The College Program

Olin Hall

Degree Offered: Bachelor of Science

College Program Committee: G. P. Fisher, chairman; R. Conway, S. Linke, M. Nelkin, R. Phelan, L. Weiss, J. Pirko.

The College Program is devised to give engineering students an opportunity to pursue novel and interdisciplinary courses of study. Students whose educational needs and career objectives cannot be satisfied by one of the Field Programs the College offers may choose to enter the College Program. In it they will develop their own program of studies consistent with their own special interests.

Each College Program is highly individualized, and is worked out between the student and his advisers. All College Programs, however, consist of an engineering major and a minor. Majors are possible in each of the Fields of engineering and in the Departments of Computer Science, Geological Sciences, and Theoretical and Applied Mechanics. The minor may be from any of the above Fields or departments, or from another unit of the University. Students have developed minors from course offerings of the College of Agriculture and Life Sciences, the College of Architecture, Art, and Planning, the College of Arts and Sciences, the School of Industrial and Labor Relations, and the College of Human Ecology.

In planning a College Program, a student should carefully consider his future educational and professional objectives, and in particular the prerequisites for any formal graduate study in which he may be interested.

Graduates of the College Program have continued their education in physical sciences, medicine, business, and law as well as in engineering. Some recent examples of major and minor combinations are: airphoto interpretation and conservation or geology; computer science and electrical systems or industrial engineering; electrical engineering and industrial engineering; electrical systems and biological science or computer science; engineering science and aerospace engineering, biological science, or materials science; environmental quality and ecology; environmental systems and city planning or regional planning; industrial engineering and computer science; materials science and biological science or chemistry; mechanical engineering and biological science or oceanography; and transportation and regional planning.

Partially structured programs sponsored by groups of interested faculty members are listed below.

Admission

Students apply to enter the College Program at the beginning of the second term of the sophomore year. Entry is in the junior year, after all requirements of the Division of Basic Studies have been met. Included in the application materials will be a statement of objective and a term-by-term listing of the courses the student proposes to take to meet his objective. It is expected that the student will develop this program with the help of technical consultants in the fields of his proposed major and minor, after discussing his objective with a member of the College Program Committee. The technical consultants may be professors recommended to the student by College Program Committee members, or professors whom he has encountered on his own.

Application forms may be obtained from the College Program Office, Olin Hall. After the application has been endorsed by the professors representing the proposed major and minor areas, it is submitted to this Office and is then either approved or disapproved by the College Program Committee.

Degree Requirements

Once admitted to the College Program, the student progresses under the supervision of the College Program Committee. His advisers are the faculty members who endorsed his program, and any course changes must be approved by them. A change in the major or minor area must be approved by the Committee, which is responsible for all of the administrative functions normally performed by the faculty of a Field Program.

Specific requirements for the Bachelor of Science degree in a College Program are: (1) An approved program of fourteen courses, seven of which are in engineering. These must carry a minimum of forty-two credit hours, of which twenty-one are to be in engineering subjects. (2) Four liberal studies elective courses, giving a minimum of twelve hours of credit. (3) Two courses, giving a minimum of six hours of credit, which are free electives.

Special Sponsored College Programs

College Program in Bioengineering

A student who is interested in bioengineering or engineering-oriented premedical preparation usually will find it advantageous to follow one of the organized bioengineering options offered within the Field Programs. If the Field options do not provide a suitable program, an individualized College Program may be formulated with the assistance of a member of the Bioengineering Committee.

College Program in Computer Science

A student interested in concentrating in the area of computer science during his upperclass years should consult with a faculty member from the Department of Computer Science, who will help in formulating an appropriate College Program. A minimum grade-point average of 2.5 is usually required. A typical computer science major might consist of the following courses offered by the Department of Computer Science. (Descriptions of these courses may be found on pp. 89–93.)

ICS211, Computers and Programming (engineering core science)
ICS280, Discrete Structures
ICS321, Introduction to Numerical Analysis
ICS410, Data Structures
ICS481, Introduction to Theory of Computing
ICS611, Programming Languages
ICS612, Translator Writing
ICS613, Systems Programming and Operating Systems

There is considerable flexibility in devising a College Program in Computer Science. Courses other than the ones listed above may be taken, depending on the student's interests.

College Program in Energy Conversion

Students desiring a broadly based engineering curriculum aimed at meeting the accelerating energy needs of society may consider the College Program in Energy Conversion, which combines elements of three conventional disciplines: nuclear, thermal, and electrical engineering. Interested students should consult a member of the faculty group sponsoring the College Program in Energy Conversion: K. B. Cady and D. D. Clark, Ward Laboratory of Nuclear Engineering; B. J. Conta and F. K. Moore, Upson Hall; and S. Linke and C. B. Wharton, Phillips Hall.

A typical curriculum is outlined below. This sample curriculum assumes that the student has taken IMG221, Thermodynamics, and IEE210, Introduction to Electrical Systems, as two of his sophomore engineering core sciences.

Term 5
IAA350, Advanced Engineering Analysis I
IMF323, Fluid Mechanics
IEE315, Electrical Laboratory I
IPC201, Nuclear Energy and the Environment
Liberal Studies Elective

Term 6
IAA351, Advanced Engineering Analysis II
IMP455, Energy Conversion
IEE316, Electrical Laboratory II
IPC303, Nuclear Science and Engineering
Liberal Studies Elective

Term 7
IMF324, Heat Transfer and Transport Processes
IEE651, Electric Energy Systems I
IPC612, Nuclear Reactor Theory I
Free Elective
Liberal Studies Elective

Term 8
IMP441, Power Systems
IEE652, Electric Energy Systems II
IPC651, Nuclear Measurements Laboratory
Free Elective
Liberal Studies Elective

By use of electives and substitutions and with attention to prerequisites, it is possible for the student to include several of the following:

IEE671, Feedback Control Systems I
IEE672, Feedback Control Systems II
IEE680, Elementary Plasma Physics and Gas Discharges
IEE681, Introduction to Plasma Physics
IMF636, Turbomachinery
IMP442, Pollution Control in Power and Propulsion
IMP643, Combustion Theory
IMG656, Advanced Thermal Engineering Laboratory
IPC633, Nuclear Reactor Engineering
IPC634, Nuclear Engineering Design Seminar

College Program in Engineering Science

Faculty members of the Department of Theoretical and Applied Mechanics have formulated a program in engineering science which they are prepared to endorse. The program has the general format outlined below.

Term 5
Engineering Science
Thermodynamics
Math or Engineering Analysis*
Physics or Engineering Science
Liberal Studies Elective

Term 6
Engineering Science
Fluid Mechanics
Math or Engineering Analysis*
Physics or Engineering Science
Liberal Studies Elective

Term 7
Physics or Engineering Science
Math or Engineering Analysis*
Intermediate Dynamics
Free Elective
Liberal Studies Elective

Term 8
Physics or Engineering Science
Math or Engineering Analysis*
Continuum Mechanics
Free Elective
Liberal Studies Elective

* Substitution of a one-year course in experimental mechanics or physics for a one-year course in mathematics may be arranged.

A further discussion of this program may be found on p. 57.

College Program in Geological Sciences

Students who are interested in concentrating in some aspect of earth science during the upperclass years should consult with a faculty member from the Department of Geological Sciences at the earliest opportunity.

A student with a prospective major in geological sciences is encouraged to take IGE101–102 (Introductory Geological Science) as an elective in the Basic Studies Program. During the junior and senior years, a typical major curriculum includes the core courses listed below, plus appropriate sequences of courses chosen from offerings in mathematics, physics, chemistry, biology, or various engineering disciplines. The selection is made on the basis of the student's interests and plans for a career. A summer course in field geology is strongly recommended.

The core courses in geological sciences are:

IGE325, Structural Geology and Sedimentation
IGE345, Geomorphology
IGE355–356, Mineralogy, Petrology, and Geochemistry
IGE376, Stratigraphy and Historical Geology
IGE386, Geophysics and Geotectonics

College Program in Public Systems Planning and Analysis

A program in Public Systems Planning and Analysis has been formulated by the faculty of the Department of Environmental Engineering of the School of Civil and Environmental Engineering. The core courses for this program, shown below, should be supplemented by additional work in the student's major area of interest, such as transportation, urban planning, or systems analysis. A number of these courses may have been taken previously in the Division of Basic Studies.

Systems Analysis Courses:
IOC320 or IOE622
IOC361 or IOC623

Economics Courses:
IIB201 or IIF611 or Economics BEC307
IIB202 or IIF612 or Economics BEC308
One additional upper-level course in economics (e.g., Economics BEC301, BEC335, or BEC351; or Consumer Economics and Public Policy PCP480

Students who have previously taken BEC101 and BEC102 can fulfill this program requirement in economics by taking IIB201 or IIF611 or BEC307 and one additional upper-level course.

Probability and Statistics Courses:
IOA260
IOC370

Applications Courses:
Public systems analysis: IIF617 and IIF618
Transportation: e.g., IIF620 or IIF621
Law and public policy: e.g., IIF605, IIF606, IIB203, Public Planning and Regional Analysis APP425 or APP452, Biological Sciences OBA203, Law MLA591 or MLA600, or Government BGO313.
City and regional planning: e.g., Public Planning and Regional Analysis APP410, or Urban Planning and Development AUP410 or AUP613
Environmental quality: e.g., IEE301 and IEE633

Computer Science

(Colleges of Engineering and of Arts and Sciences)

Upson Hall

Degrees Offered: Master of Science, Doctor of Philosophy.

G. Salton, chairman; J. R. Bunch, R. L. Constable, R. W. Conway, J. E. Dennis, Jr., D. Gries, J. Hartmanis, J. E. Hopcroft, W. L. Maxwell, C. G. Moore III, J. Moré, C. Pottle, R. E. Tarjan, R. J. Walker, J. H. Williams.

Courses of instruction are listed on pp. 89–93.

Computer science is a relatively new field of study that draws on and contributes to a number of other disciplines such as mathematics, engineering, linguistics, and psychology. Developments in this field are also useful in research, development, design, and management activities in the various functional areas of engineering and applied science.

At Cornell, computer science is concerned with fundamental knowledge in automata, computability, programming languages, and systems programming, as well as with subjects (such as numerical analysis and information processing) which underlie broad areas of computer applications. Because of the wide implications of research in the field, the Department of Computer Science is organized as an intercollege department in the College of Arts and Sciences and the College of Engineering.

Computing Facilities

The principal computing facility at Cornell is an

IBM 360 Model 65, located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus and directly linked to satellite computers at three different campus locations. The College of Engineering is served through one of these satellite stations in Upson Hall as well as by a number of teletypewriter terminals in different locations. An IBM 1800 computer is also available to provide an analog-digital interface and graphical display equipment.

The Degree Programs

The Undergraduate College Program

Although the Department teaches a comprehensive set of undergraduate courses, there is no undergraduate field program in computer science in the College of Engineering. To major in computer science the student may utilize the College Program leading to the degree of Bachelor of Science (see p. 37 for a description of a typical College Program in Computer Science). Each program must be approved after formulation by the student and cannot be specified in an approved form in advance; students interested in a computer science major should consult with a computer science faculty adviser who will help in formulating the appropriate College Program.

Master of Science and Doctor of Philosophy

In the Field of Computer Science, qualified graduate students can earn Master of Science and Doctor of Philosophy degrees.

Graduate students who are interested in the theory, design, and use of automatic computing equipment as a subject in itself should consider the opportunities for advanced training in computer science. In general, they are expected to have a strong background in mathematics, science, or engineering, although students with exceptional records from other fields will also be considered for admission. Students with an interest in the application of computers to their own major fields should consider a graduate minor in computer science to supplement their major field of study. Opportunities for research and study exist in the following areas of computer science: numerical analysis; programming languages and systems; automata and computability theory; information organization and retrieval; and analysis of algorithms.

The program for the M.S. degree involves one year of graduate-level course work and the writing of a thesis. Before the degree is awarded, a candidate must pass a comprehensive examination covering his course work and his thesis.

A Ph.D. program usually involves approximately two years of graduate-level course work, the demonstration of ability to read scientific literature in one foreign language (usually French, German, or Russian), the passing of a comprehensive oral examination, the writing of a dissertation, and a final oral examination on the dissertation. The dissertation must demonstrate the ability of the candidate to conduct an original and independent investigation of high quality and to present the results of the research in a well-organized and cogent manner.

It is possible to obtain the Ph.D. degree without first receiving the M.S. degree, or to obtain the M.S. only. Further information about the Department's teaching and research activities is summarized in an *Announcement* titled *Graduate Study in Engineering and Applied Science* (see p. 4 for the address). Prospective candidates may communicate with the Field Representative, Department of Computer Science, Upson Hall.

Electrical Engineering

Phillips Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Electrical), Master of Science, Doctor of Philosophy.

H. J. Carlin, director; J. L. Rosson, assistant director; P. D. Ankrum, J. M. Ballantyne, T. Berger, P. Bergmans, H. D. Block, R. Bolgiano, Jr., N. M. Brice, N. H. Bryant, R. R. Capranica, G. C. Dalman, L. F. Eastman, W. H. Erickson, D. T. Farley, T. L. Fine, J. Frey, F. Jelinek, M. Kim, W. H. Ku, C. A. Lee, R. L. Liboff, S. Linke, R. A. McFarlane, H. S. McGaughan, P. R. McIsaac, J. A. Nation, B. Nichols, R. E. Osborn, E. Ott, C. Pottle, H. G. Smith, L. B. Spencer, R. N. Sudan, G. Szentirmai, C. L. Tang, R. J. Thomas, J. S. Thorp, H. C. Torng, N. M. Vrana, C. B. Wharton, G. J. Wolga.

Courses of instruction are listed on pp. 93–104.

The curriculum leading to the degree of Bachelor of Science in the Field Program of the School of Electrical Engineering is intended to give an understanding of the meaning and the application of those physical laws that are basic to electrical engineering and, at the same time, to provide for the student the opportunity for as much study in the fields of humanities and social studies as is consistent with the objectives of modern education in the field of engineering. The successful completion of this degree program qualifies the student to pursue one of three possible routes to advanced studies.

1. Graduate studies in the Field of Electrical Engineering leading to the degree of Master of Engineering (Electrical). This degree is awarded for successful completion of a structured curricular program and is intended for a student who expects to practice electrical engineering as a profession but does not plan to engage in research as a career. (See p. 11 for a general description of requirements.)

2. Graduate studies leading to the degree of

Master of Science or Doctor of Philosophy. Either of these degrees involves residence on the campus and submission of a thesis and is intended for students who plan to engage in research as a career. The requirements for this degree are described in the *Announcement of the Graduate School.*

3. Advanced studies in nonengineering fields such as law and medicine.

The education of the modern electrical engineer, as represented by the successful completion of the requirements for the degree of M.Eng. (Electrical), provides a sound foundation for him to practice electrical engineering successfully in a rapidly expanding field which includes such areas as random, time variable, linear, and nonlinear systems and circuits; information theory; quantum electronics; plasma physics; magnetohydrodynamic power generation; space communication and control systems; design of switching circuits; digital processing of signals; computer-aided design; microwave propagation; radio physics; digital circuits, integrated circuits, and solid state microwave devices; and bioelectronics. In establishing this curriculum, the faculty of the School of Electrical Engineering has recognized the enormous scope of electrical engineering today and has concluded that adequate preparation in electrical engineering requires education in three main areas: *Electrophysics, Systems,* and *Laboratory.* The curriculum contains an integrated series of required courses in each of these interrelated areas.

Electrophysics is chiefly concerned with the physical laws that govern the design or application of electrical devices. Modern devices from machines to lasers are based on principles and properties of electric and magnetic fields, interaction of fields and particles, fluid flow, kinetic theory, thermodynamics, quantum mechanics, solid state, plasmas, and bioelectronics. In the curriculum, these subjects are treated in significant depth and breadth. All undergraduate students enrolled in the Electrical Engineering Field Program are required to complete IEE313, IEE314, and IEE411 as a sequence of electrophysics courses.

The *Systems* sequence deals with the laws that govern the interaction of devices whose individual behavior is specified, the response of these systems to various inputs, and the design of systems to perform a variety of functions. These systems may be solely electrical or involve transducers; they may contain both linear and nonlinear elements; they may be passive, active, random, lumped, or distributed. The program is designed to develop competence in the general methods of analysis required for such systems, understanding of the physical significance of the solutions, and knowledge of some aspects of the design of systems for power distribution, computation, control, electronic circuits, communications, pattern classification, instrumentation, and biological systems. All undergraduate students enrolled in the Electrical Engineering Field Program are required to complete IEE311, IEE312, and IEE410 as a sequence of courses in the systems area of study.

The *Laboratory* sequence emphasizes the concept that new developments in engineering practice come from a blend of theory and experimentation. Laboratory work in systems and electrophysics includes experiments in electronic circuits, instrumentation, machinery, electromagnetics, microwaves, solid state devices, computer applications, simulation and modeling, deterministic and random signal channels, etc. Each of the third-year laboratory courses involves two laboratory periods each week. Sufficient time and flexibility are provided to allow for individual exploration, and the goal is to enable the student to devise his own experiments. All undergraduate students enrolled in the Electrical Engineering Field Program are required to complete IEE315, IEE316, and six additional hours of electrical engineering electives with laboratory.

Laboratory and Research Facilities

A wide variety of excellent facilities are available for both undergraduate and graduate students enrolled in the Field of Electrical Engineering. Most of the undergraduate and graduate instruction is given in Phillips Hall, a modern building with more than 100,000 square feet of floor space. In addition to the classrooms, offices for faculty and graduate students, conference rooms, and machine and electronics shops, there are two undergraduate laboratory areas. Each laboratory is served by a stockroom containing the most modern electrical and electronic equipment and related instruments needed to implement the laboratory sequence of courses. A number of electrical engineering laboratories are devoted solely to graduate studies and research programs. Among these are laboratories for research in systems and networks, including control systems, analog computers, and switching circuits; microwave electronics, bioelectronics, physical and solid state electronics, quantum electronics including high power lasers, plasma and gas discharge phenomena, and high-energy pulse power. The internationally known National Astronomy and Ionosphere Center in Arecibo, Puerto Rico, is used for research studies of the upper atmosphere and for radio-astronomy and radar-astronomy research. Facilities at the Observatory include two radar transmitters, each having a peak-power output of 2,500,000 watts and operating in conjunction with a 1,000-foot-diameter antenna.

The Degree Programs

Bachelor of Science

Entry into the Field of Electrical Engineering comes after completion of the first two undergraduate years in the Division of Basic Studies. The upperclass program of study is outlined below.

Term 5	*Hours*
IEE311, Analysis of Electrical Systems I	4
IEE313, Electromagnetic Fields and Waves	4
IEE315, Electrical Laboratory I	4
Liberal Studies Elective	3
Technical or Free Elective*	3
Term 6	
IEE312, Analysis of Electrical Systems II	4
IEE314, Electromagnetic Fields and Waves	4
IEE316, Electrical Laboratory II	4
Liberal Studies Elective	3
Technical or Free Elective*	3
Term 7	
IEE410, Random Signals in Systems†	4
IEE411, Quantum Theory and Applications†	4
E. E. Elective with laboratory	3 or 4
Liberal Studies Elective	3
Technical or Free Elective*	3
Term 8	
E. E. Elective with laboratory	3 or 4
E. E. Elective‡	3 or 4
E. E. Elective‡	3 or 4
Liberal Studies Elective	3
Technical or Free Elective*	3

* During enrollment in the Electrical Engineering Field Program, a student must satisfactorily complete two technical and two free electives. The order in which these elective requirements are fulfilled is the student's choice.

† Upon petition to the Faculty Committee, a student may be allowed to substitute an appropriate technical course for one of these required courses.

‡ Students having special career goals may propose appropriate technical or professional electives to substitute for the Electrical Engineering electives. The approval of the adviser is required for such substitutions.

A wide selection of elective courses in the Field of Electrical Engineering is available to fourth-year students. The Field electives are listed below, with the former course numbers given in parentheses for convenience.

Theory of Systems and Networks

IEE420 (4450), Bioelectric Systems
IEE621 (4453), Introduction to Biomechanics, Bioengineering, Bionics and Robots
IEE623 (4475), Active and Digital Network Design
IEE624 (4478), Computer Methods in Electrical Engineering
IEE625 (4575), Computer Aided Network Design
IEE721 (4503), Theory of Linear Systems
IEE722 (4504), Theory of Nonlinear Systems
IEE723 (4571), Network Analysis
IEE724 (4572), Network Synthesis

Electronics

IEE430 (4430), Introduction to Lasers and Optical Electronics
IEE432 (4412), Solid State Physics and Applications
IEE531 (4431), Electronic Circuit Design
IEE532 (4432), Electronic Circuit Design
IEE631 (4433), Semiconductor Electronics I
IEE632 (4434), Semiconductor Electronics II
IEE633 (4437), Solid State Microwave Devices and Subsystems I
IEE634 (4438), Solid State Microwave Devices and Subsystems II
IEE635 (4537), Integrated Circuit Technology
IEE636 (4538), Circuit Design for Integration
IEE731 (4531), Quantum Electronics I
IEE732 (4532), Quantum Electronics II
IEE733 (4533), Opto-Electronic Devices
IEE734 (4534), Nonlinear Optics
IEE735 (4535), Solid State Devices I
IEE736 (4536), Solid State Devices II
IEE737 (4631), The Physics of Solid State Devices I
IEE738 (4632), The Physics of Solid State Devices II

Power Systems and Machinery

IEE551 (4441), Contemporary Electrical Machinery I
IEE552 (4442), Contemporary Electrical Machinery II
IEE553 (4443), Power System Equipment
IEE554 (4444), High Voltage Phenomena
IEE651 (4445), Electric Energy Systems I
IEE652 (4446), Electric Energy Systems II

Communications, Information, and Decision Theory

IEE661 (4473), Coding Algorithms
IEE662 (4474), Fundamental Information Theory
IEE663 (4476), Statistical Aspects of Communication
IEE664, Decision Making in Pattern Classification
IEE761 (4507), Random Processes in Electrical Systems I
IEE762 (4508), Random Processes in Electrical Systems II
IEE763 (4674), Advanced Information Theory
IEE764 (4672), Foundations of Inference and Decision Making
IEE765 (4673), Principles of Analog and Digital Communication

Computing Systems and Control

IEE671 (4481), Feedback Control Systems I
IEE672 (4482), Feedback Control Systems II
IEE673 (4483), Analog Computation
IEE674 (4484), Analog-Hybrid Computation
IEE675 (4487), Switching Circuits and Logic Design
IEE676 (4488), Computer Structures
IEE771 (4505), Estimation and Control in Discrete Linear Systems
IEE772 (4506), Optimal Control and Estimation for Continuous Systems
IEE773 (4681), Random Processes in Control Systems

Radio and Plasma Physics and Electromagnetic Theory

IEE581 (4461), Wave Phenomena in the

Atmosphere
IEE582 (4462), Radio Engineering
IEE680 (4464), Elementary Plasma Physics and Gas Discharges
IEE681 (4561), Introduction to Plasma Physics
IEE682 (4564), Advanced Plasma Physics
IEE683 (4511), Electrodynamics
IEE684 (4514), Microwave Theory
IEE685 (4551), Upper Atmosphere Physics I
IEE686 (4552), Upper Atmosphere Physics II
IEE687 (4565), Radiowave Propagation I
IEE688 (4566), Radiowave Propagation II
IEE689 (4567), Antennas and Radiation
IEE781 (4661), Kinetic Theory
IEE782 (4664), Nonlinear Phenomena in Plasma Physics

The scholastic requirement for electrical engineering students is a minimum grade-point average of 1.8 in third- and fourth-year courses. A student failing to make satisfactory progress toward his degree, as evidenced by a low average, by course failures, or by low grades in major courses, may be allowed an additional term in which to meet the scholastic requirements, or may be suspended from the School.

Master of Engineering (Electrical)

The purpose of this degree program is to offer depth of study in both comprehensive and specialized electrical engineering subjects and to offer study which can extend the abilities of the electrical engineer to other fields.

The general requirements for the degree are given on p. 11. Specific requirements for the M.Eng. (Electrical) degree include a minimum of four courses in advanced electrical engineering, consisting of two approved pairs chosen from a designated list on file with the M.Eng. (Electrical) adviser.

The required engineering design project is accomplished on an individual basis, and a formal report must be submitted. Design projects are often sponsored by industry or governmental agencies. Recent projects have included the design of an electric automobile, a radio deer-tracking system for conservation purposes, and a remotely controlled vehicle for exploring planetary surfaces.

There are no residence requirements, although all course work must, in general, be completed under Cornell University staff instruction. The degree requirements must normally be completed within a period of four calendar years. A minimum grade-point average of 2.5 must be maintained.

Master of Science and Doctor of Philosophy

The requirements for the degree of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School.* These are research degrees that involve residence on the campus and submission of a thesis.

In the School of Electrical Engineering, research work leading to these degrees may be undertaken in the area of *electrophysics* including radio propagation, radio and radar astronomy, electromagnetics, plasma physics, magnetohydrodynamics, physical and microwave electronics, microwave solid state devices, materials science and solid state physics in electrical engineering, quantum electronics and laser optics, biomedical electronics, electric power conversion, electrical breakdown phenomena, etc., or in the area of *systems* including information theory, network theory, communications systems, control systems, switching circuits, digital networks, computers and computer-aided design, cognitive systems, etc. A number of fellowships, research assistantships, and teaching assistantships are available to candidates for the M.S. and Ph.D. degrees who are doing their thesis research in the School of Electrical Engineering.

A description of the Field and some of the research projects now being conducted at the School is included in a special *Announcement, Graduate Study in Engineering and Applied Science* (see p. 4). Further information may be obtained from the Graduate Field Representative, School of Electrical Engineering, Phillips Hall.

Environmental Engineering

See p. 32.

Geological Sciences

(Colleges of Engineering and of Arts and Sciences)

Kimball Hall

Degrees Offered: Bachelor of Science, Master of Science, Doctor of Philosophy.

J. E. Oliver, chairman; J. M. Bird, A. L. Bloom, B. Bonnichsen, J. L. Cisne, B. L. Isacks, D. E. Karig, G. A. Kiersch, W. B. Travers, D. L. Turcotte.

Courses of instruction are listed on pp. 104–108.

Study in geological sciences is offered for students who are preparing to be professional geologists, for those who wish a broad background in the geological sciences as preparation for careers in other fields, or for those who wish to combine geological training with other sciences such as agronomy, astronomy and space science, biological sciences, chemistry, economics, mathematics, physics, or various fields of engineering. The organization of the Department of Geological Sciences as an intercollege department in the College of Arts and Sciences and the College of Engineering facilitates the structuring of individualized programs of study.

At the graduate level, interdisciplinary programs lead to the Master of Science and Doctor of Philosophy degrees in geological sciences. The Department maintains a number of strong research programs, with the new theory of plate tectonics serving as the common focus for many of them.

Geological sciences may be studied also as a minor subject in the Master of Engineering degree program (see p. 11).

The Department recommends that its students have strong preparation in mathematics and the basic sciences or engineering; for students with such training, transfer to geological sciences at any level is encouraged. The curriculum is designed to accommodate students who have no introductory education in geology but are otherwise well qualified.

Laboratory and Research Facilities

The outlook of the Department is global in scope, and its activities are widespread.

A network of seismographs is operated in the Tonga-Fiji area of the South Pacific. Seismic activity along the Alpine Fault in New Zealand is surveyed by field parties using portable seismographs. An extensive collection of microfilms of records of the World Wide Network of Standardized Seismograph Stations is available for studies of earthquakes throughout the world. A variety of geophysical instrumentation is available.

Investigations in oceanography and marine geology may be pursued aboard research vessels or at a marine laboratory operated by Cornell at the Isles of Shoals off the New Hampshire coast.

Field sites in Labrador, in Newfoundland, and in various parts of the United States are available for research in structural geology, tectonics, sedimentation, petrology, engineering geology, mineral deposits, and areal and regional geology. The Committee for Labrador Studies has been sponsoring research in Labrador for forty years, and projects are in progress on field mapping, glacial geology, and petrography. The Department has a cooperating agreement with the Museum of Northern Arizona at Flagstaff, for accommodating research projects and investigators in a varied field setting.

The Ithaca region is particularly suited for research in stratigraphy, paleontology, geomorphology, and glacial geology, and the nearby Adirondack area is a classic one for studies in metamorphic and igneous petrology.

At Cornell the Department maintains well-equipped geological sciences laboratories, which are augmented by special and advanced equipment available through other units of the University. An outstanding reference collection of minerals, ores, fossils, and recent mollusks is available. Facilities are also available to the specialized investigator at the Paleontological Research Institution, a private organization, located near the campus.

The Degree Programs

The Undergraduate College Program

In the College of Engineering, a major in geological sciences may be taken in the upperclass years through the College Program (see p. 38). Each Program is formulated on an individual basis by the student in consultation with his faculty adviser, and must be approved by the College Program Committee.

Master of Science and Doctor of Philosophy

The program of graduate study in the Field of Geological Sciences is designed to give broad training in both the field and the laboratory.

A major subject may be selected from the following: economic geology; engineering geology; environmental geology; geobiology; paleontology and stratigraphy; geochemistry, mineralogy, petrology; geomorphology; geophysics; geotectonics and structural geology; marine geology; physical geography; and seismology.

Minor subjects for students with a major in geological sciences are selected from Pleistocene geology; hydrogeology; sedimentation; and oceanography, or from other areas such as agronomy, botany, engineering, chemistry, mathematics, physics, materials science, water resources, zoology, the biological sciences, or certain nonscientific fields. Ph.D. degree candidates select at least one minor subject outside the Field. Cooperative graduate programs in many interdisciplinary areas are available.

Detailed information about the M.S. and Ph.D. programs is given in the *Announcement of the Graduate School*, and a description of graduate study opportunities in geological sciences is included in the *Announcement, Graduate Study in Engineering and Applied Science* (see p. 4). Further information may be obtained by writing to the Graduate Field Representative, Geological Sciences, Kimball Hall.

Industrial Engineering and Operational Research

Upson Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Industrial). The programs in this Field are administered by the School of Industrial Engineering and Operations Research. The Graduate Field of Operations Research offers the Master of Science and Doctor of Philosophy degrees; see p. 55.

B. W. Saunders, director; R. N. Allen, R. E. Bechhofer, L. J. Billera, M. Brown, R. W. Conway, P. M. Dearing, Jr., M. J. Eisner, D. R. Fulkerson, H. P. Goode, S. C. Jaquette, W. F. Lucas, W. L. Maxwell, G. L. Nemhauser, S. Saltzman, M. W. Sampson, T. J. Santner, A. Schultz, Jr., D. G. Severance, S. Stidham, Jr., M. J. Todd, L. I. Weiss.

Courses of instruction are listed on pp. 108–113.

Modern industrial engineering has been defined as the design, improvement, and installation of integrated systems of men, materials, and equipment; the principles and methods of engineering analysis and design are used to specify, predict, and evaluate the results to be obtained from such systems. The scope and methods of industrial engineering have expanded greatly within the last decade in response to new and increased needs of public and private organizations and the availability of new tools and skills. Twenty years ago nearly all industrial engineering was practiced in the manufacturing phase of the mechanical goods industries. With the modern expansion of the field, many new terms of identification are used instead of simply industrial engineering. Today, Cornell's program in industrial engineering encompasses areas such as operations research; manufacturing, production, and automation engineering; and even human engineering. Students are prepared to be systems engineers, management or administrative engineers, and operations engineers. Graduates are working in the areas of transportation, distribution, military logistics, weapons systems analysis, finance, public health, and the service industries, as well as in manufacturing.

The curriculum in industrial engineering at Cornell offers the student a wide range of opportunity beyond the traditional mechanical manufacturing technology. Many students are unsure of their career goals or unfamiliar with the multitude of opportunities available in industry, government, or service activities, and the curriculum has been developed with this in mind. The scientific basis and methodology which underlie applications in all fields are emphasized, rather than any particular technological orientation. For those students who have well-defined goals, however, ample elective choices are provided so that they can begin the process of specialization. Because of the flexibility and diversity of the program, it appeals to a broad range of students and leads to an even broader range of career opportunities.

Laboratory and Research Facilities

The School of Industrial Engineering and Operations Research is housed in Upson Hall, where available facilities include a remote terminal of the University's IBM 360 Model 65 computer (see p. 38). The School is one of the principal users of the University's Computing Center, which constitutes a basic laboratory for students of industrial engineering and operations research. Computer-based work is especially important in upperclass courses and in graduate research. Many research problems and projects in engineering design are supplied by industrial plants located in the area, by University operations, and by community activities.

The Degree Program

Bachelor of Science

The first two years of undergraduate study are administered by the Division of Basic Studies (see p. 23). Students may enter the Field of Industrial Engineering and Operations Research in the junior year.

During the sophomore year, a student who plans to major in industrial engineering and operations research must elect, as one of his four engineering core sciences, Introductory Engineering Probability IOA260 (formerly 9160). If a second core science from the mathematics group is desired, IOA213 (formerly 9113) would be an excellent choice, although it is not required. Another good choice might be Computer Science ICS211 (formerly 202), since it is required in the fifth term of the IE/OR program if it has not been taken during the sophomore year. Other core science choices would depend on the goals of the individual student. Early consultation with an IE/OR faculty member or with the director can be especially helpful in making appropriate choices.

In the junior year (the first in the Field), the following program of courses is required so that the student will be prepared for the options that are available in the fourth year.

Term 5	*Hours*
IOC320, Optimization Methods I (prerequisite: Mathematics BMA293)	4
IOC350, Cost Accounting, Analysis, and Control	4
IOC370, Introduction to Statistical Theory with Engineering Applications (prerequisite: IOA260)	4
ICS211, Computers and Programming*	3
Liberal Studies Elective	3
Term 6	
IOC321, Optimization Methods II (prerequisite: IOC320)	3
IOC361, Probabilistic Models in IE/OR (prerequisite: IOA260)	4
IOC383, Applications of Computer Science in IE/OR (prerequisite: ICS211)	4
Behavioral Science†	3
Liberal Studies Elective	3

* If ICS211 is completed during the sophomore year, an appropriate three-credit-hour technical elective may be substituted by agreement with the IE/OR adviser.

† The behavioral science requirement can be satisfied by any one of several courses of an advanced nature. Possible courses include

Business and Public Administration NBB520, NBB521, or NBF602 (formerly 120, 121, and 502). Industrial and Labor Relations QOB121 also covers many of the necessary topics. The adviser must approve the selection in all cases.

The Fourth Year Flexibility. Because modern industrial engineering and operations research covers such a wide spectrum of interests, and because students approaching their fourth year of study have begun to identify their particular interests, optional sequences covering the major areas of specialization are offered for the senior year program. Each student selects two sequences from the four that are available.

In addition, one technical elective, one liberal studies elective, and one free elective are chosen each term. The technical electives can be selected from the optional sequences, or can be additional mathematical courses or appropriate technological courses. The free electives can be selected from the offerings of any division of the University, but are frequently used to satisfy prerequisite requirements of Cornell's Graduate School of Business Administration or other professional schools.

The basic curriculum for the fourth year, from which individualized programs are developed, comprises the following courses:

	Hours
Four courses consisting of two two-course sequences as described below	minimum of 12
Two technical electives (these need not be sequential)	6
Two liberal studies electives	6
Two free electives	6

The available sequences are:

	Hours
Industrial Systems: IOC410 and IOC411	8
Information Systems: ICS410 and IOE682	8
Optimization Methods: IOC437 and IOC335 (For those students who are somewhat better prepared, IOE730 and IOE640 may be substituted for one or both of these courses.)	8
Applied Statistics: IOC471 and IOE672 (For some students, IOE670 may be substituted for one of these courses.)	6

Students who have established specific career goals and wish to apply the IE/OR methodology in other technological areas, such as mechanical engineering, manufacturing processing, environmental engineering, public systems, healthcare systems, or urban systems, may substitute a course sequence appropriate to the outside discipline for one of the required IE/OR sequences. This option, together with an appropriate choice of technical electives, enables a student to earn at least twelve credit hours in a technological field other than IE/OR. Through an appropriate choice of free electives also, as many as eighteen credit hours can be earned in the secondary discipline.

The IE/OR program is designed to provide a rigorous basic analytical methodology and yet be flexible enough to accommodate individual goals. Early and frequent consultation with a faculty adviser is extremely helpful to a student in planning a good fourth year program.

Advanced Study. Many IE/OR students plan to continue their studies in Cornell's Graduate School of Business and Public Administration, and some plan to study in the Graduate Field of City and Regional Planning. Although there is no formal process of double registration in the College of Engineering and in one of these graduate Fields, it is possible for students to accrue as much as a year's work toward the graduate degree (M.B.A. or M.R.P.) while they are still undergraduates. This is accomplished by making application and taking qualifying examinations at the right time, and by choosing electives carefully. In order to take advantage of these possibilities, the student should consult, during the third year of undergraduate study, the director of the School of Industrial Engineering and Operations Research and the admissions office of the appropriate professional school.

College Program. Some students prefer to emphasize one particular facet of industrial engineering and operations research, such as statistics, probability, or mathematical programming, and combine this limited analytical material with studies in another area, such as biology, computer science, mathematical economics, econometrics, or chemical or environmental engineering. Such diversity can be achieved through a College Program, which permits the student to choose a major and a minor field of study in a completely planned upperclass curriculum. It should be noted, however, that such objectives can usually be met within the flexible IE/OR Field Program.

Academic Requirements. Scholastic requirements for the Field are a passing grade in every course, maintenance of a grade-point average of at least 2.0, and satisfactory progress toward completion of the degree requirements. The student's performance is reviewed at the conclusion of each term.

Graduate Programs

At the conclusion of the four-year program, students who wish to continue their studies in the broad field of systems engineering or in operations research may apply for one of three graduate programs available at Cornell. The Graduate Field of Operations Research offers programs that emphasize research and basic theoretical content and lead to the M.S. or Ph.D. degrees (see pp. 55–57 for a description of these programs.) Those students who are interested in applied operations research in general systems engineering—whether in industry, government, or the service sectors—are advised to apply for the program leading to the professional degree of Master of Engineering (Industrial).

Master of Engineering (Industrial). This one-year professional degree program is application-oriented rather than research-oriented, and requires completion of an engineering project. The course work centers on additional study of analytical techniques, with particular emphasis on engineering applications, especially in the design of new or improved man-machine systems, information systems, and control systems. In addition to the project, which carries eight hours of academic credit, the curriculum includes a minimum of twenty-two credit hours of required or relevant elective course work.

This program is integrated with the Cornell undergraduate degree program in industrial engineering and operations research, and students who apply during their senior year will generally be admitted if their past performance indicates the ability to do graduate work. Since there is some interchangeability in the applications courses available during the fourth and fifth years, careful planning of the work is needed and early consultation with an adviser is recommended.

Requests for admission from Cornell undergraduates in engineering programs other than the IR/OR Field Program are welcome. Also considered are non-Cornellians who hold a baccalaureate degree in a field of engineering from an institution of recognized standing, have adequate preparation for graduate study in industrial engineering, and show promise of doing well in advanced study. Students from these groups may require one or possibly two additional terms to complete the degree requirements.

A minimum of thirty graduate course credits acceptable for the degree must be earned at Cornell after the award of the baccalaureate degree. A cumulative average of at least 2.5 is generally regarded as the minimum level required for admission and for the award of the degree at the completion of the program.

The required courses are:

	Hours
IOE621, Production Planning and Control	4
IOE626, Mathematical Models	4
IOE680, Digital Systems Simulation	4
IOE898–899, Project Work	8
IOE793–794, Seminar	2
Appropriate elective courses in engineering	minimum of 8

Materials Science and Engineering

Bard Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Materials), Master of Science, Doctor of Philosophy.

H. H. Johnson, director; D. G. Ast, R. W. Balluffi, B. W. Batterman, J. M. Blakely, M. S. Burton, L. DeJonghe, P. S. Ho, E. J. Kramer, C. Y. Li, A. L. Ruoff, S. L. Sass, D. N. Seidman.

Courses of instruction are listed on pp. 113–117.

In all areas of modern technology, advances in system efficiency and economy are often limited by the properties of available materials. Significant technological breakthroughs in diverse fields such as structures, power, communications, propulsion, chemical processing, or transportation frequently are a direct result of improvements in materials—either the development of new materials or the evolutionary improvement of existing ones.

As the field exists today, it is perhaps best described as a fusion of the traditional interests of the metallurgist with the basic understanding and wide scientific interest of the solid state physicist and chemist. The distinguishing "theme" of this field is the relation between the structure of materials and their properties. The structure of solids encompasses such specific aspects as crystalline structure and imperfections, molecular arrangement, phase composition and morphology, and grain size. These and other characteristics from the atomic to the macroscopic scale control the behavior of a material. Materials science is concerned with the understanding of these characteristics and with methods of influencing them, and materials engineering deals with applications, particularly with the selection, processing, characterization, and testing of materials.

Laboratory and Research Facilities

The Department of Materials Science and Engineering is centered in Bard Hall and occupies parts of Thurston and Kimball Halls, a total area of 50,000 square feet. Bard Hall, the newest of the Cornell engineering buildings, was completed in 1963 and is extensively equipped for both undergraduate and graduate instruction and research. Facilities for characterizing and studying the structure of solids by physical measurement, microscopy, metallography, and x-ray diffraction are available. Included is equipment for processing materials by casting, welding, heat treatment, compacting and sintering, deformation, and many of the newer processing procedures such as crystal growth and deposition from the vapor phase. Laboratories for preparing and studying nonmetallic materials, especially ceramics, are also housed in Bard Hall.

This Department participates with other departments of the University in the interdisciplinary Materials Science Center. The Center supports central facilities in Bard, Thurston, and Clark Halls for service and research in metallography, x-ray diffraction, electron microscopy, mechanical testing, and effects of high temperature and high pressure on materials. The Materials Science Center also supports service facilities for producing, characterizing, and testing various metallic and nonmetallic materials.

The Degree Programs

Bachelor of Science

The upperclass curriculum in Materials Science and Engineering builds upon the engineering science, physics, mathematics, and chemistry courses of the Division of Basic Studies. The Department does not require any particular engineering science course in the sophomore year as a prerequisite for entry into the upperclass program.

The courses which comprise the Field Program are supplemented by the two technical electives, two free electives, and four liberal studies electives that are required for all upperclass students in the College. Students are therefore able to incorporate a wide variety of scientific and engineering studies into their curricula. The Field courses need not be taken according to a rigid pattern. Various combinations and sequences are possible, depending to some extent upon the student's particular interests, and his elective choices in the sophomore year. Faculty advisers of the Department assist each student in planning a suitable program and selecting appropriate elective courses.

The required Field courses are listed in the following example of a program in Materials Science and Engineering:

Term 5	*Hours*
ITK331, Structure and Properties	4
ITK335, Thermodynamics of Condensed Systems	3
ITK333, Research Involvement I or a Field-approved technical elective	3
Free Elective	3
Liberal Studies Elective	3
Term 6	
ITK336, Kinetics, Diffusion, and Phase Transformations	3
ITK440, Macro-Processing of Materials	3
ITK334, Research Involvement II or a Field-approved Technical Elective	3
Free Elective	3
Liberal Studies Elective	3
Term 7	
ITK445, Electrical and Magnetic Properties of Materials	3
ITK441, Micro-Processing of Materials	3
ITK443, Senior Laboratory I*	3
Technical Elective	3
Liberal Studies Elective	3
Term 8	
ITK446, Mechanical Properties of Materials	3
ITK448, Current Topics in Materials	3
ITK444, Senior Laboratory II*	3
Technical Elective	3
Liberal Studies Elective	3

* One term of Senior Laboratory may be replaced by Physics BPS360, Introductory Electronics, or by a one-term project in association with a faculty member.

Features of the Field Program are:

1. The Research Involvement option allows students who may be interested in a research/development career to acquire a first-hand exposure to this kind of activity relatively early in their academic careers. A student with this interest affiliates with a faculty member and his research group and works on a problem of his own in the group's general field of investigation. It is necessary that a mutual interest be established between the student and a faculty member.

2. The extra technical elective in the third year provides students interested in pursuing an industrial career after receipt of the B.S. degree an additional opportunity to broaden their engineering education. This is especially important for B.S. graduates in Materials Science and Engineering, since they frequently work in collaboration with graduates of other engineering disciplines.

3. The courses in the processing of materials emphasize practical problems and applications, an area of increasing importance as international competition in technology increases.

4. The fourth-year course in Current Topics in Materials is used to acquaint students with recent developments in new areas such as bio-materials, fuel cells, composite materials, and materials problems associated with nuclear power systems. Student suggestions for desirable topics are sought in advance.

5. The Senior Laboratory courses typically require two to four experiments a term. Each experiment may take several weeks to complete. The emphasis is on student initiative in the design and execution of the experiment, with faculty supervision.

The College Program. For students wishing to combine the study of materials with some other discipline, course sequences are available to provide a major or minor program in materials science and engineering. These will be selected by the student and his adviser. (See p. 36 for an outline of the College Program.)

Master of Engineering (Materials)

A student who has completed a four-year undergraduate program in engineering or the physical sciences is eligible for consideration for admission to this program. The student will carry out an independent project that provides experience in defining objectives, planning and carrying through systematic work, and reporting conclusions. In addition, he will have the opportunity to develop further his knowledge and skill in specialized areas of materials science. The program includes the following:

1. A project qualifying for at least twelve hours of credit and requiring individual effort and initiative. This project, carried out under the supervision of a member of the faculty, is usually experimental, although it can be analytical.

2. Six credit hours of courses in mathematics or applied mathematics. This requirement may be satisfied by courses IAA350 and IAA351; students who have previously completed these must select other courses acceptable to the faculty.

3. Courses in materials science and engineering selected from any of those offered at the graduate level, or other courses approved by the faculty, required to bring the total credit hours to thirty.

Master of Science and Doctor of Philosophy

Unique opportunities are open to the student undertaking graduate study in materials at Cornell. Instruction is given in a broad spectrum of topics, ranging from the fundamental aspects of materials behavior to problems associated with materials applications. Studies of metallic and nonmetallic materials, as well as some aspects of the liquid state, are incorporated into a common framework of instruction.

The Master of Science and Doctor of Philosophy programs are primarily science-oriented programs of study directed toward a career in research, development, advanced engineering, or teaching. A candidate for either degree may choose as his major subject area either *materials science* or *materials and metallurgical engineering.* Requirements for these degrees are described in the *Announcement of the Graduate School.*

A student who enters with an undergraduate degree may register for either the M.S. or Ph.D. degree. However, it is possible for a student in the M.S. program to transfer to the Ph.D. program. Toward the end of his first year, the student's progress is reviewed by his Special Committee, and if that group takes favorable action then or at a later date, the student is accepted as a Ph.D. candidate.

The courses offered by the Field assume a sound undergraduate education in such areas as mathematics, physical metallurgy, atomic and solid state physics, and thermodynamics. Graduate students enrolled with deficiencies in any of these areas will be permitted to take intermediate-level courses, with the understanding that more time may be needed to complete the degree program.

To form an adequate foundation for more specialized courses and for thesis research, the faculty has developed a core program of courses in materials science. These cover modern theories of structure and of materials behavior at an advanced level.

A significant part of the Cornell graduate educational experience is the opportunity to participate in formal and informal seminars and research conferences at which current Cornell research programs are described and guest speakers present the latest developments in other laboratories.

An *Announcement, Graduate Study in Engineering and Applied Science,* which includes a description of graduate research and study opportunities in Materials Science and Engineering, is available upon request. Further information may be obtained from the Field Representative, Materials Science and Engineering, Bard Hall.

Mechanical and Aerospace Engineering

Upson and Grumman Halls

E. L. Resler, Jr., director; A. R. George, assistant director. P. L. Auer, D. L. Bartel, J. F. Booker, B. Conta, P. C. T. deBoer, D. Dropkin, B. Gebhart, F. C. Gouldin, A. I. Krauter, S. Leibovich, W. J. McLean, H. N. McManus, Jr., F. K. Moore, R. M. Phelan, W. R. Sears, A. R. Seebass, S. F. Shen, D. G. Shepherd, K. E. Torrance, K. K. Wang, R. L. Wehe. Members of the faculty of the Graduate Fields of Aerospace Engineering and of Mechanical Engineering are listed under the two Fields.

Courses of instruction are listed on pp. 117–126.

Aerospace Engineering

Degrees Offered: Master of Engineering (Aerospace), Master of Science, Doctor of Philosophy.

Faculty members of the Graduate Field of Aerospace Engineering: P. L. Auer, P. C. T. deBoer, R. H. Gallagher, A. R. George, G. S. S. Ludford, E. L. Resler, Jr., W. R. Sears, A. R. Seebass, S. F. Shen, D. L. Turcotte.

Aerospace engineering deals with a large variety of physical problems which have their origins in the flight of aircraft and space vehicles in atmospheric and space environments. This field has always been at the frontier of new technology, and the innovative use of the basic physical sciences has always been a necessity. The tradition of the former Graduate School of Aerospace Engineering, now part of the newly-formed Sibley School of Mechanical and Aerospace Engineering, is being maintained. The primary objective of these programs is the education and preparation of selected engineering and science graduates to enter a profession of constant challenge and high intellectual satisfaction. The training emphasizes solid fundamentals in course work and active involvement in research areas of current importance. Diversification of student interest is encouraged; close contact with the faculty provides exceptional individual attention.

Superior facilities are available for experimental studies of all types of fluid and gas dynamics, and for work in plasma physics, chemical kinetics, and laser chemistry. Theoretical investigations of both fundamental and engineering significance in these and related areas are constantly in progress. Areas of recent interest are aerodynamic noise, sonic boom, nonlinear waves, combustion processes in low-pollution engines, and solution of flow problems by finite element and numerical methods. In addition to close collaboration with the Graduate Field of Mechanical Engineering, there is close cooperation with the Laboratory of Plasma Studies, the Center for Radiophysics and Space Research, and the Center for Applied Mathematics.

Preparation for Graduate Study

Applicants will be considered for this Field if they hold baccalaureate degrees (or the equivalent) in any branch of engineering, mathematics, or the physical sciences from qualified institutions, provided that their undergraduate scholastic records indicate ability to pursue graduate study successfully.

The Cornell programs of study in engineering physics, electrical engineering, and mechanical engineering are especially recommended to undergraduates who expect to study aerospace engineering at the graduate level. The introductory courses Aerospace Engineering IMT305 and IMT306 would be useful electives. All students who expect to enter the Graduate Field of Aerospace Engineering should try to arrange their undergraduate programs to include courses in thermodynamics, fluid mechanics, applied mathematics, chemistry, and physics.

The Degree Programs

Master of Engineering (Aerospace)

Undergraduate students who have demonstrated more than average ability, have shown adequate promise for carrying on graduate study, and are interested in extending their education in the aerospace field by advanced training in analytical and research-oriented subjects are eligible for admission to this program. Candidates for a Ph.D. in this field who do not already hold a master's degree are encouraged to matriculate as candidates for the M.Eng. (Aerospace) degree.

The Master of Engineering program is designed to increase the student's facility in the application of the basic sciences to engineering problems of importance in this Field. Because aerospace engineering is continually engaged in new areas, an essential guideline for this program is to reach beyond present-day practices and techniques. This is achieved by supplying the student with the fundamental background and the analytical techniques that will prove useful in all modern engineering developments.

Successful completion of the work for this degree requires that the student pass a series of courses in approved subjects. These include two six-hour sequences in various areas of aerospace engineering. The sequences listed below represent typical ones acceptable for the degree requirements and permit candidates to study in any of four areas of aerospace engineering: (1) fluid mechanics; (2) high-temperature gasdynamics; (3) magnetohydrodynamics; and (4) theoretical aerodynamics. Active research in these areas is being carried out in the School. However, the faculty may modify this basic list to suit the needs, interests, and background of individual candidates. Other course sequences, leading to specialization in allied areas such as energy conversion, aerophysics, and chemical kinetics can be arranged.

Also required are six hours of elective subjects. In addition to those listed below, available elective subjects frequently include courses, in their specialties, offered by faculty and visiting staff members.

The other requirements for the M.Eng. (Aerospace) degree are six hours of mathematics (IAA680–681 or BMA415–416 or the equivalent), attendance at the weekly colloquium (one credit hour per term), one advanced seminar (two hours), and one advanced project (two hours). This makes a total of thirty credit hours. In unusual circumstances, exceptions may be made at the discretion of the faculty.

It is not recommended that candidates enter the program at midyear, except in very unusual circumstances. Further inquiries may be addressed to the Program Representative, M.Eng. (Aerospace), Grumman Hall.

Available courses are listed below, with the former numbers given in parentheses for convenience.

Available Course Sequences for M.Eng. (Aerospace) Degree	*Hours*
IMA611–612, Physics of Fluids I and II	6
IMA621 and IMA723 (7201 and 7203), Introductory Plasmadynamics; Intermediate Plasma Physics	6
IMF632–633, Fluid Mechanics I and II	6
IMA602–603 (7302–7303), Theoretical Aerodynamics I and II	6

*Electives: List A**	*Hours*
IAG672–673 (1772–1773), Space Flight Mechanics; Mechanics of the Solar System	6
IMA622 (7202), Introductory Magnetohydrodynamics	3
IMA704 (7304), Theory of Viscous Flows	3

IMA705 (7305), Hypersonic Flow Theory	3
IMA706 (7306), Atmospheric Motions	3
IMA707 (7307), Aerodynamic Noise Theory	3
IMA713 (7103), Dynamics of Rarefied Gases	3
IMA795, Special Topics in Aerospace Engineering	3
IMF734 (7308), Turbulence and Turbulent Flow	3

* Many of these courses are offered only if there is sufficient demand. Completion of the basic sequence or the equivalent is usually a prerequisite.

Electives: List B	*Hours*
IAA770 (1170), Foundations of Applied Mathematical Analysis	3
IAB663 (1263), Applied Elasticity	3
IAB664 (1264), Theory of Elasticity	3
IAB765 (1265), Mathematical Theory of Elasticity	3
IAC662 (1362), Vibration of Elastic Systems	3
IAC670 (1370), Intermediate Dynamics	3
IAC771 (1371), Advanced Dynamics	3
IAC675 (1375), Nonlinear Vibrations	3
IMA671 (3671), Aerospace Propulsion Systems	3
IMF737 (3677), Numerical Methods in Fluid Flow and Heat Transfer	3
IMH650 (3665), Transport Processes	3
IMH651 (3680), Convection Heat Transfer	3
IMP643 (3652), Combustion Processes	3
IMP648 (3668), Seminar on Combustion	3
IMP655 (3672), Energy Conversion	3
BPS443, Atomics and Introductory Quantum Mechanics	4
BPS444, Nuclear and High-Energy Particle Physics	4
BPS454, Introductory Solid State Physics	4
BPS510, Advanced Experimental Physics	3
BPS561, Classical Electrodynamics	3
BPS562, Thermal, Statistical, and Continuum Physics	3
BPS572, Quantum Mechanics I	3
BPS574, Quantum Mechanics II	3
BCH780, Principles of Chemical Kinetics	4
BCH796, Statistical Mechanics	4
IEE681 (4561), Introduction to Plasma Physics	3
IEE682 (4564), Advanced Plasma Physics	3
IEE731 (4531), Quantum Electronics I	3
IEE732 (4532), Quantum Electronics II	3

Master of Science and Doctor of Philosophy

Original work in aerospace engineering requires advanced courses and a thesis. This may lead to the degree of Master of Science or Doctor of Philosophy. Each student works closely with a faculty supervisor in the formulation of his individual program of course work and active research. The programs are flexible in order to accommodate the broad and changing nature of the field and the widest interests of the students, and to reflect the current needs of society and industry. This frequently results in close cooperation between the Graduate Field of Aerospace Engineering and other Fields and divisions of the University.

Faculty research in progress spreads over many areas. Fluid phenomena of diverse types have always been of prime importance. There are presently studies of the sonic boom, aerodynamic noise, ferro-fluids, geophysical flows, unsteady boundary layers, and computational fluid mechanics. Research in applied physics and chemistry are represented by topics in chemical kinetics, gas lasers, and plasmadynamics. A novel design for a low-pollution automotive engine is being intensively tested, and a new project in combustion chemistry has begun. Other projects on energy and transportation problems, some jointly with the Graduate Field of Mechanical Engineering, are under way.

The activities of the aerospace engineering faculty are best summarized through its research and published papers. Those interested in obtaining copies or abstracts of work recently completed should write to the Field Representative, Aerospace Engineering, Upson Hall. An Announcement titled *Graduate Study in Engineering and Applied Science,* which includes a description of Aerospace Engineering, is also available (see p. 4).

Mechanical Engineering

Degrees Offered: Bachelor of Science, Master of Engineering (Mechanical), Master of Science, Doctor of Philosophy.

Mechanical engineering, the broadest of the several established fields of engineering, comprises two major streams of technology: (1) the transformation and utilization of energy, including fluid dynamics and heat transfer; and (2) the design and production of goods, machines, equipment, and systems. Accordingly, mechanical engineering at Cornell falls into two main areas of concentration: Mechanical Systems and Design, and Engineering of Energy and Fluid Systems.

Because of the wide range of mechanical engineering, the four-year undergraduate program is designed to provide breadth of training, to develop in each student some depth of understanding of the engineering sciences basic to the field, and to provide him with an introduction to the professional and technical areas with which mechanical engineering is particularly concerned. The program has been designed to provide a great deal of flexibility to suit individual students' objectives.

This broad preparation leads to several possibilities for advanced study following the B.S. degree program. Possible graduate level programs at Cornell include:

1. *Graduate study leading to the degree of Master of Engineering (Mechanical).* This is a curricular type of professional program intended for those students who wish to practice

mechanical engineering. Although the course of study is available for all qualified students who hold a baccalaureate degree in engineering, the program is specially adapted as a graduate year of study integrated with the previous work in the Sibley School of Mechanical and Aerospace Engineering. It is the program commonly taken by qualified students not planning to pursue research or teaching as a career or not changing their field for advanced work. Details of this program are given on the following pages.

2. *Graduate study leading to the degrees of Master of Science or Doctor of Philosophy, with majors in either mechanical design or thermal engineering.* Students planning to engage in research or teaching as a career would normally enroll in such a program. Information is given in the *Announcement of the Graduate School.*

3. *Graduate study in related fields,* such as aerospace engineering, industrial engineering, or nuclear science and engineering, or in different fields such as business administration, law, or medicine.

Areas of Concentration

Mechanical Systems and Design. This area is concerned with those aspects of mechanical engineering that involve the design, analysis, and manufacture of devices, machines, and systems. To follow a course of study in this area, a student may elect courses that will equip him for a wide variety of engineering tasks; particular areas of concentration are vehicle engineering and manufacturing and design.

Vehicle engineering is concerned with the transportation needs of modern society. It includes the consideration of wheeled, tracked, air-cushioned vehicles, and other unconventional transporters. Dynamic and safety aspects as well as structural features are considered. The course offerings are supplemented with independent projects.

Manufacturing and design is concerned with the economical design and production of material goods needed by society. Emphasis is placed on the interrelation of design and manufacture. Attention is paid to the newer production techniques (e.g., electromechanical machining, electrodischarge machining, explosive forming, numerical control, and automated production), and the traditional methods. Independent work in specialized areas is also offered.

Engineering of Energy and Fluid Systems. This area of concentration is concerned with the transformation, transfer, and utilization of energy, and with fluid dynamics. These concerns may be summarized as:

1. *Power and propulsion:* Conversion of energy for man's various requirements for electric power and transportation (terrestrial and aerospace). Students are offered relevant elective courses treating power and aerospace propulsion systems, energy conversion, combustion and transport processes, and fluid mechanics.

2. *Environmental control:* The study of environmental modification, with emphasis on sources of pollutants, their distribution through the earth's waters and atmosphere, and technical alternatives that minimize or eliminate the impact of technologically originated pollution. The creation of artificial environments is considered. Relevant electives treat pollution problems, refrigeration and air conditioning, acoustics and noise, combustion engines, and the more fundamental topics already mentioned.

Theoretical and experimental research interests include high-temperature and nonequilibrium fluid dynamics; plasma processes; flow lasers; rotating fluids with application to the confinement of high-temperature gases and to natural processes in the atmosphere and oceans; problems of heat rejection to the environment—thermal pollution; combustion processes, air pollution, and fire research; convection, conduction, and radiative heat transfer.

The Degree Programs

Bachelor of Science

The four-year baccalaureate program in mechanical engineering begins in the Division of Basic Studies (DBS), which offers a freshman and sophomore curriculum that is substantially common to all undergraduate engineering students (see pp. 23–24). Students who plan to enter the Field Program in Mechanical Engineering as upperclassmen must elect, as one of their four sophomore engineering core sciences, the course IAK221, Mechanics of Solids. It is recommended, though not required, that they also take IMG221, Introduction to Thermodynamics, and IAK231, Dynamics, as two of their other sophomore engineering core sciences. This will allow a more flexible Field program with an increased number of elective courses.

The upperclass curriculum comprises twenty courses. Eight are required by the College for all junior and senior students, and consist of four liberal studies electives, two technical electives, and two free electives. The Field Program in Mechanical Engineering comprises the other twelve courses: nine required, one elective in the area of mathematics (chosen from a list of approved courses), and two Field electives (upperclass courses offered by the Sibley School of Mechanical and Aerospace Engineering). Of the nine required courses, three may be core sciences taken previously in DBS; in this case, released electives—chosen from offerings in the natural sciences, mathematics, or engineering—become available. Thus the Field Program provides a great deal of flexibility: a minimum of four and a maximum of eight electives in technical areas are available during the junior and senior years. This flexibility requires careful planning by the student in consultation with his faculty adviser to ensure that he follows a meaningful program directed by his particular interests.

Field Program requirements are summarized as follows.

Required courses which may be taken as core sciences in DBS or as Mechanical Engineering Field courses:
IAK231, Dynamics
ITB261, Mechanical Properties of Materials (DBS)
or
IMM311, Materials and Manufacturing Processes (Field course)
IEE210, Introduction to Electrical Systems
IMG221, Introduction to Thermodynamics

Other required courses:
IMF323, Fluid Dynamics
IMH324, Heat Transfer and Transport Properties
IMG325, Mechanical Design and Analysis
IMS326, Systems Dynamics
IMG453, Mechanical Engineering Laboratory

Elective courses:
A course in mathematics or mathematical methods, chosen from an approved list and taken during the junior or senior year.
Two Field electives selected from upperclass courses in mechanical engineering offered by the Sibley School of Mechanical and Aerospace Engineering.

A basic course sequence suitable for students who enter the Field Program with only one underclass mechanical engineering course (the entry requirement of IAK221, Mechanics of Solids) is given below as a guide to the development of a curriculum. It may be pointed out, however, that many other arrangements can be made in consultation with a faculty adviser. In particular, those students who have followed the recommendation to satisfy some Field requirements by taking certain sophomore engineering core sciences are able to substitute released electives for them.

Term 5
IAK231, Dynamics
IMG221, Thermodynamics
IMM311, Materials and Manufacturing Processes
Mathematics Elective
Liberal Studies Elective

Term 6
IMG325, Mechanical Design and Analysis
IMF323, Fluid Mechanics
IEE210, Introduction to Electrical Systems
Field Elective
Liberal Studies Elective

Term 7
IMH324, Heat Transfer and Transport Processes
IMS326, Systems Dynamics
IMG453, Mechanical Engineering Laboratory
Technical Elective
Liberal Studies Elective

Term 8
Field Elective
Technical Elective
Free Elective
Free Elective
Liberal Studies Elective

Although there is no requirement for industrial experience, undergraduate students are urged to obtain summer employment that will broaden their knowledge of engineering. This is regarded as particularly desirable for those who plan to enter the professional program for the Master of Engineering degree. The University and College placement services can be helpful in finding employment opportunities. Industrial experience is also available to mechanical engineering students through the Engineering Cooperative Program (see pp. 9–10), which provides for three work periods during the upperclass years yet does not delay the normal graduation date.

Graduate Degrees

Faculty members of the Graduate Field of Mechanical Engineering: D. L. Bartel, J. F. Booker, B. Conta, T. A. Cool, D. Dropkin, B. Gebhart, F. C. Gouldin, A. I. Krauter, S. Leibovich, W. J. McLean, H. N. McManus, Jr., F. K. Moore, R. M. Phelan, D. G. Shepherd, K. E. Torrance, K. K. Wang, R. L. Wehe.

Master of Engineering (Mechanical)

A one-year program integrated with the undergraduate degree program in mechanical engineering leads to the professional degree of Master of Engineering (Mechanical). The emphasis is on the development of competence in professional subjects. Experience is provided through a team design project.

This program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas within the Field of mechanical engineering. These areas include bioengineering, machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, thermal power, thermal environment, manufacturing engineering, and material removal. Depending on the individual's preparation, at least half the course work is elective to some degree.

Admissions requirements are listed on p. 11. A minimum of two terms of full-time study with completion of at least thirty hours of course work is required to complete the degree program. It should be noted, however, that since the program is integrated with the Cornell undergraduate program in mechanical engineering, students with other undergraduate backgrounds may have deficiencies which will necessitate additional work and perhaps more than the usual length of time to earn the degree.

The usual curriculum is as follows.

Fall Term	*Hours*
Mathematics	3
IMS761, Advanced Mechanical Analysis	3
IMG790, Mechanical Engineering Design Project	3
Engineering Laboratory	3
Technical Elective	3
Spring Term	
Mathematics	3
Advanced Energy and Fluid Systems	3
IMG790, Mechanical Engineering Design Project	3
Mechanical Engineering Elective	3
Technical Elective	3

It is recommended that the mathematics requirement be satisfied by Applied Mathematics IAA350–351 or, on a more advanced level, by IAA680–681. Courses offered by the Department of Mathematics may be taken with the approval of the adviser. If the six-hour mathematics requirement has been satisfied in advance by courses taken during the undergraduate years, these credit hours may be taken in technical elective subjects.

The schedule may be arranged to accommodate the energy and fluid systems course either term. The course is to be selected from the following: IMH650, Transport Processes (fall); IMA611, Physics of Fluids I (fall); IMP655, Energy Conversion (spring); and IMF737, Numerical Methods in Fluid Flow and Heat Transfer (spring). If two or more of these courses have been satisfactorily completed prior to entry in the program, any graduate level course in the IMF, IMH, or IMP groups may be taken to satisfy the energy and fluid systems requirement.

The engineering laboratory course may be either IMD672, Experimental Methods in Machine Design (fall), or IMG656, Advanced Energy and Fluid Systems Laboratory (fall). Other laboratory courses given in the College of Engineering may be approved for qualified students if such courses are suitable for a particular objective.

The Mechanical Engineering Design Project, IMG790, requires individuals to work as members of a design team which is responsible for the preparation of a formal report at the end of the year. Some recent projects have been concerned with fly ash disposal, application of heat pipes to automobiles, ocean current measurement, manufacture of freeze-dried coffee, gas turbine load-test equipment, pore size measurement of plastic foam, and assistive devices for hands and legs. Some projects are suggested, monitored, and reviewed by outside organizations, whose engineers work with the student project groups and participate in a technical session when the project reports are presented at the end of the year.

Some scholarship aid is available. Admission and scholarship application forms may be obtained by writing to the Office of the Chairman, Graduate Professional Engineering Programs, 221 Carpenter Hall. Further information on the program can be obtained from the Office of the Director, Sibley School of Mechanical and Aerospace engineering, 105 Upson Hall.

Master of Science and Doctor of Philosophy

The general and special requirements for these degrees in the Graduate Field of Mechanical Engineering are given in the *Announcement of the Graduate School.*

There is no required pattern of courses; an individual program of formal or informal study is arranged by a student in consultation with a Special Committee of his own selection. The required thesis study is usually related to general or special interests of a faculty member of this Field.

Fellowships, research assistantships, and teaching assistantships are available. Further information may be obtained by writing to the Mechanical Engineering Field Representative, Sibley School of Mechanical and Aerospace Engineering, Upson Hall.

Nuclear Science and Engineering

Ward Laboratory of Nuclear Engineering

Degrees Offered: Master of Engineering (Nuclear), Master of Science, Doctor of Philosophy.

Faculty of the Engineering Field of Nuclear Engineering supervising the M.Eng. (Nuclear) degree: K. B. Cady, A. P. Casarett, D. D. Clark, D. Dropkin, C. D. Gates, H. H. Fleischmann, B. S. Isacks, V. O. Kostroun, C.-Y. Li, S. Linke, F. K. Moore, M. S. Nelkin, J. S. Thorp, R. L. Von Berg.

Faculty of the Graduate Field of Nuclear Science and Engineering supervising the Master of Science and Doctor of Philosophy degrees: the persons listed above and, in addition, R. M. Littauer and G. H. Morrison.

Courses of instruction are listed under Applied and Engineering Physics on pp. 68–72.

Nuclear science and nuclear engineering are concerned with the understanding, development, and practical application of scientific knowledge of nuclear reactions and radiations.

The programs at Cornell are designed to accommodate students who are interested in *(a)* nuclear physics, *(b)* nuclear engineering, *(c)* radiation protection, or *(d)* some combination of these. Subjects in nuclear physics include low-energy nuclear structure, atomic structure, and phenomena involving interactions between nuclear and atomic processes. Nuclear engineering involves the basic sciences of chemistry, physics, and mathematics in combination with the skills of metallurgical, chemical, civil, electrical, and mechanical engineering— with the goal of designing safe, efficient nuclear energy systems. Radiation protection, nuclear safety, and environmental effects of nuclear energy utilization constitute a third important area of study; in addition to inclusion of these topics in the regular nuclear engineering courses, an undergraduate course IPC201, Nuclear Energy and the Environment, is offered, and graduate students have the opportunity to take courses in radiation biology taught in the Department of Physical Biology.

The aims of the Cornell programs are to provide the student with a thorough understanding of the scientific principles upon which nuclear systems are based, to develop the skills of applying these principles to engineering problems, and (in the M.S. and Ph.D. programs) to develop research abilities.

To implement these aims, Cornell offers three graduate degrees: a professional degree, Master of Engineering (Nuclear), administered by the Engineering Field of Nuclear Engineering, and two research degrees, Master of Science and Doctor of Philosophy, administered by the Graduate Field of Nuclear Science and Engineering.

Appropriate undergraduate programs which can lead to graduate study in nuclear science and engineering are physics, engineering physics, or civil, chemical, electrical, mechanical, or materials engineering, or a suitable set of courses in the College Program. Students should select their technical electives carefully to ensure that they meet the entrance requirements for the graduate program they intend to enter.

Laboratory and Research Facilities

The Ward Laboratory of Nuclear Engineering contains: (1) a TRIGA research reactor with a steady-state power of 100 kilowatts and a pulsing capability of 250 megawatts providing sources of neutrons and gamma rays for activation analysis, solid and liquid state studies, and nuclear physics research. In addition to standard pneumatic and mechanical transfer systems for activated specimens, the reactor is equipped with a 50 millisecond rapid transfer mechanism in one of the six beam ports; (2) a critical facility or "zero power reactor" of versatile design for basic studies of reactor physics, such as space-dependent reactor kinetics and noise analysis; (3) a 3 MV positive-ion accelerator for studies of radiation effects and low energy nuclear reactions; (4) a shielded gamma cell with 5,000 curies of Co^{60} for radiation chemistry studies; (5) a radiochemistry laboratory; and (6) subcritical assemblies for reactor physics investigations.

The Degree Programs

Undergraduate Study

Students are encouraged to begin specialization in nuclear science and engineering at the undergraduate level. This can be done by choice of electives within regular Field Programs such as Engineering Physics, or within the College Program by selection of appropriate courses with the approval of the College Program Committee.

Major in Nuclear Engineering. A student majoring in nuclear engineering under the College Program would take IPC201, Nuclear Energy and the Environment, and IPC303, Introduction to Nuclear Science. Also required would be two of the following courses: IPC612, Nuclear Reactor Theory I; IPC651, Nuclear Measurements Laboratory; IPC633, Nuclear Reactor Engineering; and IPC609, Low Energy Nuclear Physics.

College Program in Energy Conversion. This Program is a synthesis of nuclear, thermal, and electrical engineering and is described in the College Program section of this *Announcement;* see p. 37.

Master of Engineering (Nuclear)

This two-term curriculum is intended primarily for individuals who want a terminal professional degree, but it may also serve as preparation for doctoral study in nuclear science and engineering. The course of study covers the basic principles of nuclear reactor systems with a major emphasis on reactor safety and radiation protection and control. There is a growing need in the nuclear industry and the regulatory agencies for engineers who have a thorough knowledge of these safety provisions and who are able to apply it to the design of reactor plants and auxiliary equipment and to the implementation of environmental monitoring systems. Required courses in the Master of Engineering (Nuclear) program treat reactor safety and radiation protection and control in depth, and an elective course in radiation biology and an elective seminar in physical biology are available.

The background recommended for the M.Eng. (Nuclear) degree program includes: (1) a baccalaureate degree in engineering, physics, or applied science; (2) modern physics; (3) mathematics, including advanced calculus; and (4) thermodynamics.

Students should see that they fulfill these requirements before beginning the program.

In some cases, deficiencies in preparatory work may be made up by informal study during the preceding summer.

The interdisciplinary nature of nuclear engineering allows students to enter from a variety of undergraduate specializations. Our students in the past have had widely varying background preparations including physics, engineering physics, mechanical engineering, chemical engineering, electrical engineering, civil engineering, materials science and engineering, and nuclear engineering.

The thirty credit hours for the degree include the following courses:

Fall Term
IPC612, Nuclear Reactor Theory I
IPC633, Nuclear Reactor Engineering
IPC609, Low Energy Nuclear Physics
Technical Elective

Spring Term
IPC651, Nuclear Measurements Laboratory
Technical Elective
Engineering Design Project
Mathematics or Physics Elective

The engineering electives should be in a subject area relevant to nuclear engineering, such as energy conversion, radiation protection and control, feedback control systems, magnetohydrodynamics, controlled thermonuclear fusion, and environmental engineering. Typical examples of courses that might be chosen by Master of Engineering (Nuclear) degree candidates are: Physical Biology RTB922, Biological Effects of Radiation; IMP655, Energy Conversion; IMH651, Convection Heat Transfer; IEE681, Introduction to Plasma Physics; IEE682, Advanced Plasma Physics; IMA621, Introductory Plasma Physics; IMA622, Introductory Magnetohydrodynamics; and IEE671–672, Feedback Control Systems.

Admission and scholarship application forms may be obtained by writing to the Office of the Chairman, Graduate Professional Engineering Programs, 221 Carpenter Hall. Further Information on the nuclear science and engineering professional program may be obtained by writing to the Ward Laboratory of Nuclear Engineering.

Master of Science and Doctor of Philosophy

The M.S. and Ph.D. programs are oriented toward research, and require completion of a thesis as well as course work. A candidate for one of these degrees chooses either *nuclear science* or *nuclear engineering* as his major subject, but because each student plans an individual program in consultation with the faculty members of his Special Committee, there are no detailed course requirements. This approach, long a tradition of graduate study at Cornell, is well suited to interdisciplinary fields such as nuclear science and engineering. Independent thesis research along with formal and informal discussions with staff members and other students is a vital part of the program.

If a student chooses *nuclear science* as his major subject, thesis research may be undertaken in any of the following areas: nuclear structure physics, atomic physics and x-ray phenomena, nuclear astrophysics, nuclear chemistry, nuclear instrumentation, radiation chemistry, and radiation effects on materials. If he selects *nuclear engineering,* the following areas are possible: experimental and analytical reactor physics, reactor plant dynamics and safety, radiation protection and control, neutron transport theory and kinetic theory, nuclear energy conversion, nuclear environmental engineering, and nuclear structural engineering.

The appropriate preparation for graduate work in these programs is an undergraduate education in science, applied science, or engineering, with special emphasis on mathematics and modern physics.

Additional information on the M.S. and Ph.D. programs is available in the *Announcement of the Graduate School,* and the *Announcement, Graduate Study in Engineering and Applied Science* (see p. 4). Further information may be obtained from the Office of the Graduate Field Representative, Ward Laboratory of Nuclear Engineering.

Operations Research

Upson Hall

Degrees Offered: Master of Science, Doctor of Philosophy. The School of Industrial Engineering and Operations Research administers the undergraduate Field of Industrial Engineering and Operations Research and the Master of Engineering (Industrial) degree program (see pp. 43–46).

R. E. Bechhofer, chairman (on leave 1973–74); G. L. Nemhauser, acting chairman; L. J. Billera, M. Brown, R. W. Conway, P. M. Dearing, Jr., M. J. Eisner, D. R. Fulkerson, H. P. Goode, S. C. Jaquette, J. C. Kiefer, W. F. Lucas, W. R. Lynn, W. L. Maxwell, N. U. Prabhu, S. Saltzman, T. J. Santner, B. W. Saunders, A. Schultz, Jr., D. G. Severance, F. L. Spitzer, S. Stidham, Jr., H. M. Taylor, 3d, M. J. Todd, L. I. Weiss.

Courses of instruction are listed on pp. 108–113.

The Field of Operations Research offers doctoral programs in four major areas: operations research, applied probability and statistics, systems analysis and design, and industrial engineering. Master of Science programs are offered in all the above areas, and in information processing.

A general description of the five areas is given below.

Operations Research

The problem areas and techniques of operations research are approached from a highly analytical viewpoint. Emphasis is placed on constructing appropriate mathematical models to represent various real-life operational systems, and on developing techniques for analyzing the performance of these models. In this way procedures with desirable properties for dealing with such systems are developed. Queuing, inventory, reliability, replacement, and scheduling theories and simulation are employed. Optimization techniques such as mathematical programming (linear, nonlinear, and probabilistic), network flows, combinatorics, and dynamic programming are also used extensively, as are the various techniques of the mathematical theory of games.

The operations research student pursues a course of study and research that emphasizes the use of the mathematical, probabilistic, statistical, and computational sciences in the development of the techniques of operations research. His ultimate goal may range from making a fundamental contribution to the techniques of operations research to applying these techniques to problems in diverse professional fields.

Applied Probability and Statistics

This subject of study and research is designed for students having primary interests in the techniques and associated underlying theory of probability and statistics, particularly as they are applied to problems arising in science and engineering. The techniques emphasized are those associated with applied stochastic processes (for example, queuing theory, traffic theory, inventory theory, and time-series analysis) and statistics (including statistical decision theory; the statistical aspects of the design, analysis, and interpretation of experiments, and of ranking and selection theory; reliability theory; statistical quality control; sampling inspection; and acceptance sampling).

Students who elect work in this area are expected to acquire considerable knowledge of the theory of probability and statistics. All students who major in applied probability and statistics are required to minor in mathematics.

Systems Analysis and Design

Although the solution of systems problems requires knowledge of underlying theory, the inherent practical limitations of the problem must be understood. Analysis of a system alone is insufficient; alternative solutions must be generated before selection of the one which can best be integrated with other elements of the system. Modeling concepts are equally important, but only when they can produce workable systems. Illustrations of the design of integrated systems can be found in industry, the environment, commerce, and government. A good example is the design of urban traffic control systems. Research activity may involve the development of new methodology or the synthesizing of new combinations from what is already known. The goal is to improve the understanding of systems or to develop new decision criteria for systems.

Industrial Engineering

Studies of the analysis and design of the complex operational systems that occur in industry, particularly in manufacturing, are included in this subject. Plant design, cost analysis and control, and production planning are some of the major topics. A student is expected to have considerable facility in the modern analytical techniques associated with rational decision making and the establishment of valid design criteria. These techniques are drawn from among inventory theory, queuing theory, mathematical programming, quality control, and computer simulation.

Because the design and operation of modern engineering systems apply to areas other than manufacturing, the use of the word "industrial" should not be considered restrictive. Industrial engineers frequently are employed as systems specialists in commerce, banking, distribution, merchandising, and hospital management.

Information Processing

Information processing deals with the analysis and design of systems which record, transmit, store, and process information. Emphasis is on the application and integration of equipment rather than on the design of machines. Areas of interest include systems for information retrieval, manufacturing control, and traffic control. This subject also includes such underlying theoretical topics as data structure, operating system organization, and computing language structure.

The principal campus computing facility is an IBM 360/65, with on-line operation from many campus locations. A satellite 360/20, directly connected to the 360/65, is located in Upson Hall, where the Department of Operations Research is housed. Teletypewriter terminals are also in use.

The Degree Programs

Master of Science and Doctor of Philosophy

These degree programs, administered by the Graduate School of the University, are described in the *Announcement of the Graduate School.*

Major and minor subjects are chosen from those areas outlined above. Minors can also be subjects offered by other units of the University; appropriate minors that have been chosen most frequently in recent years, and the departments or schools which offer courses of study in them are: applied mathematics (Applied Mathematics), computer science (Computer Science).

econometrics and economic statistics (Economics), public systems planning and analysis (Civil and Environmental Engineering), managerial economics (Business and Public Administration), mathematics (Mathematics), and planning theory and systems analysis (City and Regional Planning).

A prerequisite for graduate study in the Field of Operations Research is a Bachelor's degree in engineering, mathematics, economics, or the physical sciences, awarded by an institution of recognized standing. The candidate must have a commendable undergraduate scholastic record and must supply other evidence of his interest in and ability to pursue advanced study and research in his proposed major and minor subjects. Submission of the results of the Graduate Record Examination is strongly recommended for all applicants and is required for fellowship and assistantship applicants.

Further information, including an *Announcement, Graduate Study in Engineering and Applied Science,* may be obtained by writing to the Graduate Field Representative, Department of Operations Research, Upson Hall.

Structural Engineering

See p. 34.

Theoretical and Applied Mechanics

Thurston Hall

Degrees Offered: Master of Engineering (Engineering Mechanics), Master of Science, Doctor of Philosophy.

K. T. Alfriend, H. D. Block, J. A. Burns, H. D. Conway, E. T. Cranch, J. C. Dunn, R. H. Lance, S. A. Levin, G. S. S. Ludford, Y. H. Pao, R. H. Rand, D. N. Robinson, W. H. Sachse.

Courses of instruction are listed on pp. 126–132.

The Department of Theoretical and Applied Mechanics is responsible for undergraduate and graduate instruction and research in theoretical and applied mechanics and applied mathematics. The subject matter in these areas is of a fundamental nature, and the undergraduate courses provide a substantial part of the basic engineering science education for engineering students. In addition to the required core courses, the undergraduate can elect advanced courses which are especially suited to students who have demonstrated superior analytical or experimental ability and who wish to extend and develop this ability. The Department offers undergraduate programs in individualized major and minor subjects through the College Program described below and on p. 37.

The Degree Programs

The Undergraduate College Program

The Department sponsors an undergraduate College Program in Engineering Science that has a science-based curriculum flexible enough to be adapted to special or developing interests. It is designed for engineering students who want flexibility in their undergraduate curricula; for students whose interests are not reflected by any of the major engineering disciplines; for students who want to emphasize basic engineering sciences; and for those who want to postpone specialization.

There are general guidelines for the curriculum, but no specific prescribed courses beyond those required of all engineering students during their first two years in the Division of Basic Studies. The idea is to develop a solid understanding of the basic science behind all engineering, and to supplement this with study in a particular area, such as astronomy, applied mathematics, physics, chemistry, or biology. A typical program is shown on page 37.

Any faculty member of the Department of Theoretical and Applied Mechanics can sponsor an individual student who wishes to plan a College Program in Engineering Science. The choice of particular courses is based on the educational goals of the student, and is made jointly by the student and his adviser.

It should be noted that this is a College-approved curriculum equivalent to a Field program. It provides the opportunity for choice of professional specialization within a sound, science-based curriculum, and it offers maximum flexibility in curriculum, since there are no specifically required courses. Further information may be obtained from faculty members of the Department.

Master of Engineering (Engineering Mechanics)

Students interested in advanced study in mechanics who intend to emphasize engineering practice rather than teaching or research may apply for admission to the M.Eng. (Engineering Mechanics) degree program. This course of study is designed to allow the student to master advanced topics in mechanics and, at the same time, to develop his facility in applying fundamental concepts in mechanics to modern engineering problems. No formal thesis is required for this degree; however, the student is required to carry out an individual project, either analytical or experimental in nature, under the supervision of a faculty member.

Admission requirements are: (1) a baccalaureate degree in engineering or applied science; and (2) a cumulative grade-point average of at least 2.5 in the undergraduate curriculum. Undergraduate programs of non-Cornellians must, in the judgment of faculty members in the Field, provide adequate preparation in mechanics.

Degree requirements are: (1) completion of a minimum of three credit hours of work on an individual project under the direction of a faculty member; (2) satisfactory completion of six credit hours of course work in mathematics or applied mathematics (which may be satisfied by the Theoretical and Applied Mechanics course sequence IAA680–681 or the equivalent); and (3) courses in or relating to theoretical and applied mechanics, selected in consultation with the student's adviser from those offered at the graduate level, to bring the total credit hours to at least thirty.

A general description of the Master of Engineering degree is given on p. 11. Further information may be obtained from members of the Department.

Master of Science and Doctor of Philosophy

These research-oriented degrees, administered by the Graduate School of the University, require submission of a thesis. A description is given in the *Announcement of the Graduate School.* A special *Announcement, Graduate Study in Engineering and Applied Science,* includes a more detailed description of the Field of Theoretical and Applied Mechanics.

The graduate program in mechanics and applied mathematics emphasizes fundamental understanding of the newest developments in engineering and applied science. The basic nature of the studies encourages research that cuts across and extends various traditional engineering fields and ensures that the specialist will find many opportunities to work, either in industry or in academic institutions, on advanced engineering projects for which conventional training is often inadequate.

Graduate students may pursue programs involving theoretical or experimental work in the following areas of specialization.

1. Space mechanics, including research on trajectories and orbits of space vehicles and satellites and on the theory of light-weight, thin-walled structures.

2. Wave propagation in solids; waves in layered media; scattering of elastic waves and dynamic stress concentrations; waves in plates, rods, and shells.

3. Structural mechanics, including the mechanics of composite materials, static and dynamic loadings; linear and nonlinear vibrations and buckling.

4. Theory of elasticity, inelasticity, and plasticity, including the effects of high-temperature environment.

5. Experimental mechanics—experimental facilities are available for research in many areas of study, including linear and nonlinear vibrations, wave propagation and damping measurements in solids, mechanical behavior of composite materials, magnetoelasticity, and photoelasticity.

6. Continuum mechanics.

7. Biomechanics and bionics; artificial intelligence and robots.

8. Theoretical fluid mechanics, with research in gasdynamics and magnetohydrodynamics.

The flexibility of the graduate study programs at Cornell permits students to draw on several divisions of the University for supporting work in pure and applied science. Graduate students interested primarily in theoretical and applied mechanics and applied mathematics find these supporting fields of interest: mathematics, structures, engineering physics, servomechanisms, machine design, aerospace engineering, soil mechanics and physics.

Additional information can be obtained by writing to the Office of the Graduate Field Representative, Theoretical and Applied Mechanics, Thurston Hall.

Thermal Engineering

See p. 48.

University Program on Science, Technology, and Society

R. Bowers, director; P. L. Bereano, executive secretary.

Students and faculty members from all parts of the University are welcome to participate in the interdisciplinary Program on Science, Technology, and Society. The purpose of STS is to stimulate and initiate teaching and research on the interaction of science and technology with contemporary society, and to provide coherence and support for current University activities in this area.

Topics of concern to the Program are illustrated by the following examples: science, technology, and national defense; science, technology, and values; legal and moral implications of modern biology and medicine; national policy for the development of science; sociology of science; the ecological impact of developing technology; and science, technology, and law. Mechanisms for studying problems such as these include courses, graduate and faculty seminars, workshops, and individual research programs. The Program is also assisting the Graduate Minor Field of Public Policy by offering a science policy "stream" within this minor Field. The following courses are cosponsored by STS in collaboration with other units of the University.

Biological Sciences OBA201, Biology and Society. Spring. S. A. Zahler and R. S. Marshall.

Biological Sciences OBA203–204, Special Topics in Social Biology. Throughout the year. S. A. Zahler and R. S. Marshall.

Business and Public Administration BPA560, Comparative Science Policies. Spring. F. A. Long and A. L. Segal.

Computer Science ICS105, The Computerized Society. Fall.

Economics BEC302, The Impact and Control of Technological Change. Spring. D. C. Mueller and D. W. Nelkin.

Engineering IIB203, Social Implications of Technology. Fall. P. L. Bereano and W. R. Lynn.

Engineering IIF605, The Law and Environmental Control. Fall. P. L. Bereano.

Engineering IIF606, Seminar in Technology Assessment. Spring. P. L. Bereano and others.

Engineering IMG102, Technology and Society—A Historical Perspective. Spring. B. J. Conta.

Government 312, Urban Politics. Spring. D. S. Van Houweling.

Government 384 (formerly 371), Defense Policy and Arms Control. Spring. F. A. Long and G. H. Quester.

Government 559 and Business and Public Administration BPA559, Science, Technology, and Public Policy in the United States. Fall. F. A. Long and A. L. Segal.

[Government 561 and Business and Public Administration BPA561, Transfers of Science and Technology from Industrialized to Developing Countries. Fall. Not offered in 1973–74.]

Government 562 and Business and Public Administration BPS640, Science, Technology, and International Relations. Fall. Offered in alternate years.

History 337 and Philosophy 337, Problems in the Philosophy and History of Biology. Fall. R. N. Boyd and W. Provine.

Law MLA591 (formerly 525), Science, Technology, and Law. Spring. K. L. Hanslowe.

Philosophy 383, Problems of Choice and Decision. Fall. M. Black.

Sociology 403, Sociology of Science and Technology. Spring. G. Gordon.

Course descriptions and a list of other relevant courses may be obtained from the Program Office, 628 Clark Hall.

Description of Courses

Descriptions of courses are listed under the division, school, or department which offers them. These units are presented in alphabetical order, except that freshman and sophomore courses offered through the Division of Basic Studies are listed first.

The listings under Basic Studies include a number of courses in mathematics and physical sciences that are offered by the College of Arts and Sciences but are required or frequently taken in the underclass engineering curriculum. Complete listings in the humanities, social sciences, and physical and natural sciences are given in the *Announcement of the College of Arts and Sciences* and other University *Announcements.* A general list of subjects offered throughout the University, with references to the various divisions that offer them, is included in the *Announcement of General Information.*

Each course title is followed by a (u) or (g) designation to indicate whether the course is intended primarily for undergraduates or for graduate students. In many instances, both undergraduates and graduates are welcome to enroll if they meet the prerequisites. Undergraduates should consult their advisers concerning eligibility for courses with graduate designations.

Each course is designated by six letters or digits which have the following significance.

First. A letter designating the college offering the course. Engineering courses, for example, begin with I; Arts and Sciences courses begin with B.

Second. A letter designating the school or department offering the course. The following code applies to engineering.

Applied and Engineering Physics	P
Basic Studies	B
Chemical Engineering	H
Civil and Environmental Engineering	I
Computer Science	C
Electrical Engineering	E
Geological Sciences	G
Industrial Engineeirng and Operations Research	O
Materials Science and Engineering	T
Mechanical and Aerospace Engineering	M
Theoretical and Applied Mechanics	A

(Agriculture Engineering courses are coded for the College of Agriculture and Life Sciences and have the first two letters OA)

Third. A letter of varying significance. In the College of Engineering this third letter often designates a related group of courses within the school or department.

Fourth. A number describing the course level.

Fifth and sixth. Numbers assigned as identification for specific courses.

Since this numbering system is being introduced this year and many students and faculty members are accustomed to the previous system of course numbering, the former numbers have been listed in parentheses following the new numbers in places where it seemed that the information would be helpful.

Basic Studies Division

IBE105 (105) Elements of Engineering Communication (u). Either term. Credit three hours. One lecture, one recitation, one laboratory.

Communication of physical concepts to others; communication with digital computers. Principles of graphics and computer programming studied through projects related to design and modeling of physical processes. Graphics emphasizes sketching to develop skill in visual communication.

IBE106 (106) Engineering Perspectives (u). Either term. Credit three hours. One lecture, one recitation, one laboratory.

Illustration of engineering point of view through detailed study of specific problems with major engineering aspects. Students choose "mini-courses" from selection offered by various faculty members throughout the College of Engineering. Small recitations and work sessions permit close contact between students and engineering faculty. Lectures will present an overview of the engineering profession.

Mathematics

BMA191 (191) Calculus for Engineers (u). Either term. Credit four hours. Prerequisite: three years of high school mathematics, including trigonometry. Fall term: lectures, M W F 9:05, 11:15 plus recitation periods to be arranged. Spring term: M W F S 9:05. In the fall term BMA191 will be run as a self-paced course; students can pass the course by taking tests for which they present themselves at a time of their own choosing. Those students who have not completed their tests before the end of the term will have to take a final examination.

Plane analytic geometry, differentiation and integration of algebraic and trigonometric functions, applications.

BMA192 (192) Calculus for Engineers (u). Either term. Credit four hours. Prerequisite: BMA191. Lectures, M W F 9:05, 11:15 plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Sept. 19, Oct. 10, Nov. 28; Feb. 13, Mar. 6, Apr. 3, Apr. 24.

Transcendental functions, technique of integration and multiple integrals, vector calculus, analytic geometry in space, partial differentiation, applications.

BMA194 (194) Calculus for Engineers (u). Spring. Credit four hours. Prerequisite: recommendation of the lecturer in course BMA191. Lectures, M W F 9:05, 11:15, recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Feb. 13, Mar. 6, Apr. 3, Apr. 24.

Covers the course content of BMA192 in more detail and includes more theoretical material.

BMA293 (293) Engineering Mathematics (u). Either term. Credit four hours. Prerequisite: BMA192 or BMA194. Lectures, M W F 12:20 and 1:25; recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. Oct. 2, Oct. 30, Dec. 4; Feb. 19, Apr. 2, Apr. 30.

Vectors and matrices, first order differential equations, infinite series, complex numbers, applications. Problems for programming and running on the automatic computer will be assigned, and students are expected to have a knowledge of computer programming equivalent to that taught in IBE105.

BMA294 (294) Engineering Mathematics (u). Either term. Credit three hours. Prerequisite: BMA293. Lectures, M W 8, 12:20; recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. Oct. 2, Oct. 30, Dec. 4; Feb. 19, Apr. 2, Apr. 30.

Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications.

BMA295 (293H) Engineering Mathematics (u). Fall. Credit four hours. Prerequisite: BMA192 or BMA194. BMA295 is an honors section of BMA293. Lectures, M W F 12:20; recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 2, Oct. 30, Dec. 4; Feb. 19, Apr. 2, Apr. 30.

Lectures follow the general plan and cover the material of BMA293, with substantially greater emphasis on fundamental unifying concepts. Additional topics may include: an introduction to convergence in metric spaces; the role of complex numbers in clarifying the behavior of real power series and real linear transformations; invariant subspaces of a linear transformation and the Jordan canonical form.

BMA296 (294H) Engineering Mathematics (u). Spring. Credit four hours. Prerequisite: BMA295 or consent of instructor. BMA296 is an honors section of BMA294. Lectures, M W F 12:20; recitation periods to be arranged.

Lectures follow the general plan and cover the material of BMA294, with substantially greater emphasis on fundamental unifying concepts. Additional topics may include: a development of the theory of linear ordinary differential equations with constant coefficient via the matrix exponential function; fundamental solution matrices for time-dependent linear ordinary differential equations; particular solutions via the superposition integral. Recitation work will include one major problem-solving project involving modeling, computer programming, and, possibly, experimental verification.

Physics

BPS112 (112) Physics I: Mechanics and Heat (u). Either term. Credit four hours. Prerequisite: coregistration in Mathematics BMA192. Lectures, M F 10:10 or 12:20. Two discussion periods each week and one two-hour laboratory period every other week to be arranged. Preliminary examinations will be held at 7:30 p.m. Oct. 2, Nov. 6; Feb. 19, Apr. 2. Primarily for students of engineering and for prospective majors in physics. Fall term, J. Burns and D. Hartill and staff; spring term, J. Silcox and staff.

The mechanics of particles; kinematics, dynamics, and introduction to special relativity, conservation laws, central force fields, and periodic motion. The mechanics of many-particle systems; center of mass, simple rotational mechanics of a rigid body, static equilibrium.

Kinetic theory of simple gases. At the level of *Fundamentals of Physics* by Halliday and Resnick.

BPS213 (213) Physics II: Electricity and Magnetism (u). Either term. Credit four hours. Primarily for students of engineering and for prospective majors in physics. Prerequisite: Physics BPS112 and Mathematics BMA192. Lectures, T Th 9:05 or 11:15. Two discussion periods each week to be arranged. One two-hour laboratory period per week to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 4, Nov. 1, Nov. 29; Feb. 26, Apr. 9. Fall term: D. M. Lee. Spring term: B. W. Batterman.

Electrostatics, behavior of matter in electric fields, magnetic fields, Faraday's Law, electromagnetic oscillations and waves, magnetism and relativity. At the level of *Fundamentals of Physics* by Halliday and Resnick. Experiments include electrical measurements and circuits, and physical electronics. Laboratory work supplements the written and oral work. Experiments deal with electrical measurements, dc and ac circuits, resonance phenomena, physical electronics, electrical conduction, and selected properties of electric and magnetic fields.

BPS214 (214) Physics III: Optics, Waves, and Particles (u). Either term. Credit three hours. Primarily for students of engineering and for prospective majors in physics. Prerequisite: Physics BPS213 and Mathematics BMA293 or BMA221; coregistration in Physics BPS216 or BPS310 required. Lectures, T Th 9:05 or 11:15. Two discussion periods each week to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 4, Nov. 8, Dec. 6; Feb. 14, Mar. 14, May 2. Fall term: R. Littauer. Spring term: D. H. White.

Wave phenomena; electromagnetic waves; physical optics; quantum effects, matter waves; uncertainty principles; introduction to wave mechanics, elementary applications. At the level of *Fundamentals of Optics and Modern Physics* by H. D. Young.

BPS216 (216L) Laboratory to Accompany Physics BPS214 or BPS218 (u). Either term. Credit one hour. Coregistration in Physics BPS214 or BPS218 required. One two-hour period to be arranged.

Experiments include optics, lasers, atomic spectroscopy, solid state, and nuclear and particle physics.

BPS217 (217) Physics II: Electricity and Magnetism (u). Fall. Credit four hours. An honors version of Physics BPS213 for those students who have done work of high quality in BPS112 and who wish to take part in a more thorough treatment of basic electricity and magnetism than that of BPS213. Students wishing to take this course should preregister for it. Acceptance into the course will be determined by the instructor. Engineering students should seek the approval of their advisers before registering. Physics majors are encouraged to register for this course in place of BPS213. Lectures, T Th S 11:15. One two-hour laboratory period a week to be arranged. J. DeWire.

A study of the fundamentals of electromagnetism based on the material in *Electricity and Magnetism* by Purcell (Vol. II, Berkeley Physics Series.)

Chemistry

BCH207–208 (107–108) General Chemistry (u). Fall: BCH207; credit three hours. Spring: BCH208; credit four hours. Enrollment limited. Recommended for those students who will take further courses in chemistry. Prerequisite: high school chemistry; BCH207 is prerequisite to BCH208. Lectures: fall, T Th 9:05, 10:10, or 12:20; spring, T Th 9:05 or 10:10 and one additional recitation to be arranged. Laboratory, T Th or F 8–11; M T W Th or F 1:25–4:25. Preliminary examinations will be held in the evening. Fall: F. R. Scholar and assistants. Spring: M. J. Sienko and assistants.

The important chemical principles and facts are covered, with considerable attention given to quantitative aspects and to the techniques that are important for further work in chemistry. Second-term laboratory includes a systematic study of quantitative analysis.

Engineering Sciences

Group I

IOA213 (9113) Systems Analysis and Design (u). Spring. Credit three hours. Two lectures, one recitation. Prerequisite: Mathematics BMA293. T. Berger.

Introduction to the modeling of systems, using the concepts of states and transitions. Emphasis is on the formulation of models common to problems in various branches of engineering. Use of graph theory, difference equations, and Markov chains to analyze and design static and dynamic systems.

IOA260 (9160) Introductory Engineering Probability (u). Either term. Credit three hours. Three lectures. Prerequisite: first year calculus. L. I. Weiss and staff.

At the end of this course a student should have a working knowledge of some of the basic tools in probability theory and their use in engineering. This course may be the last course in probability for some students or it may be followed by a course in statistics. The topics that are introduced include: a definition of probability; basic rules for calculating with probabilities when the number of possible outcomes is finite; discrete and continuous random variables; probability distribution and density functions; expected values, jointly distributed random variables, and marginal and conditional distributions; special distributions important in engineering work: the normal, exponential, binomial, Poisson, and other distributions and how they arise in practice; and Markov chains and applications.

IOA270 (9170) Basic Engineering Statistics (u,g). Either term. Credit three hours. Two lectures, one recitation. (Graduate students will be assigned to a separate recitation section.) Students who intend to enter the upperclass Field of Industrial Engineering and Operations Research should take IOA260 instead of this course. Prerequisite: first year calculus. Staff.

At the end of this course a student should command a working knowledge of basic statistics as it applies to engineering work. For many students this will be the only course in statistics they will ever take. For students who wish to learn more about statistics, a course in probability (e.g., IOA260) followed by a course in statistics (e.g., IOC370) are recommended. The topics are: graphical and numerical methods of representing data—histograms and cumulative frequency polygons, sample means and variances; basic tools of probability, discrete and continuous random variables, probability distribution and density functions, expected values and "population" moments, special distributions—the normal, chi-square, binomial, and others; tests of "significance" and one- and two-sided hypothesis tests concerning the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; point- and confidence-interval estimation; correlation and curve fitting by least squares.

ICS211 (202) Computers and Programming (u). Either term. Credit three hours. Prerequisite: ICS100 or equivalent programming experience. Lectures, M W 9:05 or T Th 10:10. Laboratory, M T W Th or F 2:30–4:25.

Intended as a foundations course in computer programming. Algorithms and their relation to computers and programs. Analysis of algorithms in terms of space and time requirements. A procedure-oriented language: specification of syntax and semantics, data types and structures, statement types, input-output, program structure. A brief introduction to machine organization. Programming and debugging problems on a computer are an essential part of this course.

Group II

IEE210 (4210) Introduction to Electrical Systems (u). Either term. Credit three hours. Three lecture-recitations. Prerequisite: Mathematics BMA192 and Physics BPS112.

Intended to develop competence in several analysis skills appropriate to the field of electrical engineering and to impart understanding of the physical basis for the concepts associated with the skills. Topics include: electrical circuit elements (resistors, capacitors, inductors, independent sources, and branch relationships); time functions and their representation (real exponentials, complex numbers, trigonometric functions, and complex exponentials); response of simple networks and the impedance concept (natural response, forced response to periodic excitation and pole-zero concepts); circuit equations and methods of solution (branch equations, Kirchhoff's laws, nodal and mesh equations, matrix methods of solution, and Norton and Thevenin equivalents); controlled sources and modeling of devices (representation of idealized electronic and electromechanical devices).

ITB262 (6262) Introduction to Electrical Properties of Materials (u). Spring. Credit three hours. Two lectures and one recitation or laboratory.

Description and understanding of physical properties and applications of electrical materials. Electronic structure of atoms, molecules, and crystalline solids. Energy band concept applied to insulators, semiconductors, and metals. Semiconductors and applications in electronic devices. Thermoelectricity, dielectrics, and magnetic properties.

IPK217 (8117) Contemporary Topics in Applied Physics (u). Spring. Credit three hours. Prerequisite: Physics BPS213. The course will consist of lecture periods combined with recitations and some experiments. Lectures, M W 10:10 or M W 12:20. Recitation-laboratory, M T W Th or F 2:30–4:25. V. O. Kostroun and staff.

Selected examples of contemporary applications of modern physics will be studied. The objective is to develop a semiquantitative understanding of the underlying physical principles and phenomena and the intrinsic limits they place on applications. Discussion will also include the interplay between physics and other factors (technological, scientific and, when relevant, social) which set limits on application of modern physics and influence its development. For example, nuclear energy utilization may be studied in terms of the physics of fission, fusion, and plasmas, along with the technological and social factors affecting development of nuclear energy sources. Applications of physics in other sciences such as astrophysics and biology may also be studied.

Group III

IAK201 (1001) Introduction to Applied Mechanics (u). Either term. Credit three hours. Two lectures, one recitation a week; four laboratory sessions per term. Prerequisite: registration in Mathematics BMA293. Students may not receive credit for both IAK201 and IAK221, or for both IAK201 and IAK231.

An integrated treatment of the mechanics of solids and fluids for students in engineering, life sciences, and interdisciplinary programs. Consists of an introduction to the fundamental concepts of statics, dynamics, continuum mechanics, and the properties of materials, with application of these concepts in discussions of several practical examples drawn from solid and fluid mechanics. These include the torsion, bending, and buckling of structural members, time-dependent and statical problems in elasticity and fluids at rest, perfect fluids, and fluids with friction.

IAK221 (1021) Mechanics of Solids (u). Either term. Credit three hours. Two lectures, one recitation, demonstration laboratory four times per term. Prerequisite: registration in Mathematics BMA293.

Principles of statics, force systems, and equilibrium. Mechanics of deformable solids, stress, strain, statically determinate and indeterminate problems. Analysis of slender bars, shearing force, bending moment, singularity functions. Plane stress, transformation of stress, Mohr's circle of stress and strain. Stress-strain-time-temperature relations, elasticity, plasticity, viscoelasticity. Bending and torsion of slender bars, stresses, deformations, and plastic behavior. Virtual work, energy methods, and applications.

IAK231 (1031) Dynamics (u). Either term. Credit three hours. Two lectures, one recitation; demonstration laboratory four times a term. Prerequisite: registration in Mathematics BMA293.

Principles of Newtonian dynamics of a particle, systems of particles, and a rigid body. Kinematics, frames of reference, motion relative to a moving frame, impulse, momentum, energy. Laws of motion of a system, center of mass, total kinetic energy, moment of momentum, constraints. Rigid body kinematics, angular velocity, moment of momentum and the inertia tensor, Euler equations, the gyroscope. Advanced methods in dynamics. Generalized coordinates, Lagrange's equations, the potential energy function, the kinetic energy function, applications. At the level of *Applied Mechanics-Dynamics* by Housner and Hudson.

ITB261 (6261) Introduction to Mechanical Properties of Materials (u). Either term. Credit three hours. Two lectures, one recitation or laboratory.

Elastic, anelastic, and plastic behavior of crystalline and rubber-like materials, single and polycrystalline materials. Stress-thinning mechanisms, composite materials; fracture, fatigue, and creep. Crystal structure, lattice defects, phase equilibria, diffusion, macrostructure and microstructure from programmed learning sequences. Engineering applications of materials.

Group IV

Several courses in physical and organic chemistry offered by the Department of Chemistry in the College of Arts and Sciences at Cornell qualify as engineering core sciences.

BCH287–288 (287–288) Introductory Physical Chemistry (u). Fall: BCH287. Spring: BCH288. Credit three hours a term. Prerequisite: Chemistry BCH208 (formerly 108) or consent of instructor; BCH287 is prerequisite to BCH288. Lectures, W F 9:05; occasional lectures, M 9:05. Recitations, M W or F 1:25. Examinations may be given M 9:05 or evenings. Fall: E. L. Elson and assistants. Spring: R. E. Hughes and assistants.

A systematic treatment of the fundamental principles of physical chemistry.

BCH289–290 (289–290) Introductory Physical Chemistry Laboratory (u). Fall. BCH289. Spring: BCH290. Credit two hours a term. Prerequisite: BCH289 is prerequisite to BCH290. Coregistration in Chemistry BCH287–288 is required. Laboratory lecture, S 9:05. Laboratory, M T or W Th 1:25–4:25 or, if warranted by sufficient registration, F 1:25–4:25 and S 10–1. First hour of laboratory on M W or F devoted to BCH287 recitation. Fall: A. C. Albrecht and assistants. Spring: R. R. Rye and assistants.

The development of needed skills in experimental aspects concerned with the fundamental principles of physical chemistry.

BCH357–358 (357–358) Introductory Organic Chemistry (u). Fall: BCH357. Spring: BCH358. Credit three hours a term. Prerequisite: Chemistry BCH208 or advanced placement in chemistry; BCH357 is prerequisite to BCH358. Preliminary examinations may be held in the evening. Lectures, M W F 9:05. Fall: D. A. Usher.

A systematic study of the more important classes of carbon compounds, reactions of their functional groups, methods of synthesis, relations, and uses.

IMG221 (3631) Thermodynamics (u). Either term. Credit three hours. Three recitations. Prerequisite: Mathematics BMA191 and BMA192, Physics BPS112.

The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, multiphase pure substances, gaseous mixtures, and gaseous reactions. Heat-engine and heat-pump cycles. An introduction to statistical thermodynamics.

IHE110 (5111) Mass and Energy Balances (u). Either term. Credit three hours. Prerequisite: one year of freshman chemistry or consent of instructor. R. G. Thorpe.

Content is the same as for IHE111, but this course uses *only self-paced audiovisual instruction at the convenience of the student.* A minimum of seventy clock hours of audiovisual instruction is required to master the subject matter. Student performance is evaluated by nine tests, two preliminary examinations, and a final examination. Superior students may earn exemption from the final examination.

Aerospace Engineering

See p. 117.

Agricultural Engineering

(For a complete description of the courses in agriculture, see the *Announcement of the College of Agriculture and Life Sciences.)*

OAE151 (152) Introduction to Agricultural Engineering Measurements (u). Spring. Credit three hours or, if taken after OAE221, two hours. One lecture, two laboratories. Prerequisite: one term of calculus or concurrent registration. G. Levine.

A study of the principles and methods of engineering measurements. Fundamentals of measurements, sources of errors, and measurement systems, including surveying measurements, will be considered. An appropriate computing language and elementary statistics will be taught as an integrated part of the solution of agricultural engineering measurement problems.

OAE152 (153) Engineering Drawing (u). Fall. Credit three hours. Two lectures, one laboratory. H. A. Longhouse.

Designed to promote an understanding of the engineer's universal graphic language. The lectures will deal primarily with spatial relationships involving the problem-solving techniques of descriptive geometry. The laboratories will develop a working knowledge of drawing conventions, standard and advanced drafting techniques, and their application to machine, architectural, and pictorial drawing problems. Graphs and engineering graphics (nomography and graphical calculus) will also be included. Students will accomplish their work with drafting machines as well as the standard T-square and board. The first half hour of the laboratory will be utilized as an instruction-recitation period.

OAE415 (410) Physical Analysis of Plant and Animal Materials (u,g). Spring. Credit two hours. Two lectures. Prerequisite: one semester of calculus. G. E. Rehkugler.

A study and analysis of the physical properties of plant and animal materials. The definition of pertinent physical properties and development of the meaning of a physical property. The morphology of plant and animal materials will be related to problems of defining physical properties. Specifically, material product geometry will be examined and the influence of forces on behavior of materials will be studied. Physical properties of plant and animal materials will be related to material and manipulative forces applied in growth, harvesting, processing and handling. The deformation and flow of these materials will be modeled. Interpretation of physical properties of plant and animal materials will be used in defining texture of food materials, and mechanical damage to plant products.

OAE416 (411) Laboratory Practice in Physical Analysis (u,g). Spring. Credit one hour. May be taken without OAE415 by permission of the instructor. One laboratory-recitation. Prerequisite: one semester of calculus. Laboratories and recitations will be offered in alternate weeks. G. E. Rehkugler.

Laboratory component of course OAE415. Laboratory practice will be in the physical analysis of plant and animal materials.

OAE325 (421) Introduction to Environmental Pollution (u,g). Spring. Credit three hours. Two lectures, one two-hour discussion every other week. D. C. Ludington.

A general course dealing with the impairment of the environment by the wastes of man. The causes and effects of air, water, and soil pollution will be discussed. Fundamental factors underlying waste production, abatement, treatment, and control will be included. A selected number of wastes from urban, rural, and industrial areas will be used to illustrate the factors.

OAE401 (450) Special Topics in Agricultural Engineering (u). Spring. Credit one hour. Open only to seniors. W. W. Gunkel.

Presentation and discussion of the opportunities, qualifications, and responsibilities for positions of service in the various fields of agricultural engineering.

[**OAE461 (461) Agricultural Machinery Design (u,g).** Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: mechanical design and analysis. W. W. Gunkel. Not offered in 1973–74.

The principles of design and development of agricultural machines to meet functional requirements. Emphasis is on computer-aided analysis and design, stress analysis, selection of construction materials, and testing procedures involved in agricultural machine development. Engineering creativity and design related to agricultural production systems are also stressed.]

OAE462 (462) Agricultural Power (u,g). Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: engineering mechanics (dynamics), or equivalent. G. E. Rehkugler.

Utilization of internal combustion engine and other forms of energy in agriculture. Basic theory, analysis, and testing of internal combustion engines for use in farm tractors and other agricultural power applications. Specific study of tractor transmissions. Nebraska Tractor Tests, and soil mechanics related to traction and vehicle mobility. Economics and human factors in power use and application will be considered.

[**OAE465 (463) Processing and Handling Systems for Agricultural Materials (u,g).** Spring. Credit four hours. Three lectures, one laboratory. R. B. Furry. Not offered in 1973–74.

Processes such as size reduction, separation, metering, and drying will be studied. Psychrometrics, fluid flow measurement, and an introduction to dimensional analysis and controls for agricultural applications are included. Problem solutions will employ both the analog and digital computers. It is preferred that the student know how to write programs to utilize the digital computer, prior to enrolling in the course.]

OAE471 (471) Soil and Water Engineering (u,g). Fall. Credit three hours. Two lectures, one discussion-laboratory. Prerequisite: fluid mechanics or hydraulics and soils, or concurrent registration; farm management recommended. R. D. Black.

The application of engineering principles to problems of soil and water management. Design and construction of drainage, irrigation and erosion control systems, small reservoirs and earth embankments.

OAE475 (475) Systems Models for Environmental Quality Control (u,g). Spring. Credit three hours. Prerequisite: one year of college mathematics. Three lectures. D. A. Haith.

Introduction to the use of systems analysis techniques in the study of environmental quality problems. The course will emphasize the role of mathematical modeling as a technique for identifying alternative means of satisfying environmental quality objectives. The techniques of simulation and linear and dynamic programming will be applied to such areas as water quality control, solid waste management, air pollution control, and agricultural wastes. Students will be encouraged to select course projects from their fields of interest.

OAE481 (481) Agricultural Structures Design (u,g). Spring. Credit two hours. Prerequisite: structural engineering. One lecture, one recitation-laboratory. N. R. Scott.

Application of basic structural concepts to design of agricultural structures. Emphasis on wood structures, including design of trusses, rigid frames, prefabricated panels, and columns. Design of reinforced concrete members and steel members. Economic considerations are presented also.

OAE482 (482) Environmental Control for Animals and Plants (u,g). Spring. Credit two hours. Prerequisite: thermodynamics. One lecture, one recitation-laboratory. N. R. Scott.

Study of thermal interchanges between animals, including man, and plants with the environment. Understanding of physiological principles affecting thermal comfort and health. Ventilation, air conditioning, psychrometrics, insulation, condensation control, solar energy, and weather phenomena.

OAE491 (491) Highway Engineering (u,g). (Same as Civil and Environmental Engineering IID632.) Offered upon sufficient demand, usually in the fall term. Credit three hours. Prerequisite: permission of instructor. Principally directed study and individual or team investigations with one 2½-hour session a week, to be arranged. L. H. Irwin.

Emphasis is on secondary roads in study of: economic considerations in road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

OAE492 (492) Bituminous Materials and Pavement Design (u,g). Usually offered in spring term. Credit three hours. Prerequisite: permission of instructor. One three-hour class session a week with six to nine laboratory meetings per term. L. H. Irwin.

Properties of asphalts, aggregates, and bituminous mixtures; bituminous mixture design; pavement construction; pavement maintenance; flexible pavement design methods; rigid pavement design methods.

OAE551–552 (551–552) Agricultural Engineering Project (g). Credit six hours. Required for M.Eng. degree. G. E. Rehkugler and staff.

Comprehensive design projects utilizing real engineering problems to present fundamentals of agricultural engineering design. Emphasis on formulation of alternate design proposals, including economics and nontechnical factors and complete design of the best alternative.

OAE651 (501) Similitude Methodology (g). Spring. Credit three hours. Two lectures, one laboratory. R. B. Furry.

Similitude methodology, including the use of dimensional analysis to develop general equations to define physical phenomena; model theory; distorted models; and analogies; with an introduction to a variety of applications in engineering. Problem solutions will employ both analog and digital computers. It is preferred that the student know how to write programs to utilize the digital computer, prior to enrolling in the course.

OAE652 (502) Instrumentation (g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: permission of instructor. N. R. Scott.

Emphasis is on the application of instrumentation concepts and systems to physical and biological measurements. Characteristics of instruments, application of operational amplifiers and transistors for signal conditioning and interfacing, shielding and grounding; transducers for measurement of force, pressure, displacement, velocity, acceleration, temperature, light, and flow; and data acquisition systems, including telemetry, are considered.

[OAE675 (505) Solid Waste Management (u,g). (Same as Civil and Environmental Engineering IIE630.) Spring. Credit three hours. Prerequisite: permission of instructor. R. C. Loehr. Not offered in 1973–74.

Study of municipal, industrial, and agricultural solid wastes. Emphasis on waste characteristics, method of treatment, and disposal, and interrelationship with air, water, and land environment. Discussion of economic and political aspects. Intended primarily for graduate students but open to qualified undergraduates.]

OAE676 (506) Industrial Waste Management (u,g). (Same as Chemical Engineering IHE622 and Civil and Environmental Engineering IIE631.) Spring. Credit three hours. Primarily a graduate course, but open to upperclassmen in Chemical, Agricultural, or Civil and Environmental Engineering, or in the College Program with a major from these fields.

Offered jointly with Chemical Engineering and Civil and Environmental Engineering as an integrated presentation. The first third of the course is concerned with legal aspects, assimilatory capacity of receiving waters, joint industrial-municipal collection of wastes, and sewerage service charges. The second part covers waste sampling and analysis, treatment processes, waste-reduction possibilities, water quality and quantity, water reuse and recovery, and costs. The final third of the course includes specific industrial operations and selected case studies of industrial waste treatment. A study, in depth, of a particular waste problem is required of all students.

OAE677 (507) Treatment and Disposal of Agricultural Wastes (u,g). Spring. Credit three hours. For graduate students and seniors. Prerequisite: permission of instructor. R. C. Loehr.

Emphasis is on the causes of agricultural waste problems and on the fundamentals and application of possible treatment and disposal practices to control the problems. The purpose is to have students understand how to make decisions about the selection and utilization of appropriate agricultural waste management processes and systems, as well as how to design and operate the systems. Aerobic and anaerobic processes, nutrient control, waste utilization, and land disposal are discussed. The students apply these and other concepts to the management of wastes from specific animal and crop production and food processing operations. Discussion of the integration of feasible waste management methods into agricultural production constitutes a major part of the course.

OAE678 (510) Environmental Quality Management for Agro-Ecosystems (g). (Same as Civil and Environmental Engineering IIF751.) Fall. Credit three hours. Prerequisite: some knowledge of linear programming or permission of instructors. C. Shoemaker and D. A. Haith.

The application of systems analysis and mathematical ecology to problems in ecosystem management and environment quality. Topics to be considered will be selected from the following: pest control, fertilizer usage, eutrophication, agricultural waste, soil and water conservation, and public policy decisions affecting ecosystem management.

OAE685 (504) Biological Engineering Analysis (g). Spring (usually offered in the fall). Credit four hours. Three lectures. Prerequisite: IAA351 or consent of instructor. J. R. Cooke.

Engineering problem-solving strategies and techniques will be explored. The student will solve several representative engineering problems which inherently involve biological properties. The mathematical modeling will emphasize problem formulation and interpretation of results. The student's knowledge of fundamental principles will be extensively utilized. Principles of feedback control theory will be applied to biological systems.

OAE700 (601) Agricultural Engineering Seminar (g). Fall and spring. Staff.

Presentation and discussion of research and special developments in agricultural engineering and other fields.

OAE761 (602) Power and Machinery Seminar (g). Spring. Credit one hour. Prerequisite: permission of instructor. Staff.

Study and discussions of research and new developments in agricultural power and machinery.

OAE771 (603) Soils and Water Engineering Seminar (g). Spring. Credit one hour. Prerequisite: permission of instructor. Staff.

Study and discussion of research on selected topics in irrigation, drainage, erosion control, and agricultural hydrology.

OAE775 (605) Agricultural Waste Management Seminar (g). Fall and spring. Credit one hour. Prerequisite: permission of instructor. Staff.

Study and discussion of the management of agricultural waste, with emphasis on the physical, chemical, biological, economic, and aesthetic requirements.

OAE781 (604) Agricultural Structures and Related Systems Seminar (g). Spring. Credit one hour. Prerequisite: permission of instructor. Staff.

Study and discussion of farmstead production problems, with emphasis on biological, economic, environmental, and structural requirements.

OAE785 (606) Biological Engineering Seminar (g). Spring. Credit one hour. Prerequisite: permission of instructor. N. R. Scott and J. R. Cooke.

The interaction of engineering and biology will be examined, especially the environmental aspects of plant, animal, and human physiology, in order to improve communications between engineers and biologists.

Applied and Engineering Physics

IPK751 and IPK752 (8051 and 8052) Project (g). Fall and spring. Credit three hours.

Informal study under direction of a member of the University staff. The objective is to develop self-reliance and initiative, as well as to gain experience with methods of attack and with overall planning in the carrying out of a special problem related to the student's field of interest.

IPK490 (8090) Informal Study in Engineering Physics (u,g). Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the staff.

IPK217 (8117) Contemporary Topics in Applied Physics (u). Spring. Credit three hours. Prerequisite: Physics BPS213. Lecture periods combined with recitations and some experiments. Lectures, M W 10:10 or M W 12:20. Recitation-laboratory, M T W Th or F 2:30–4:25. V. O. Kostroun and staff.

Selected examples of contemporary applications of modern physics will be studied. The objective is to develop a semiquantitative understanding of the underlying physical principles and phenomena and the intrinsic limits they place on applications. Discussion will also include the interplay between physics and other factors (technological, scientific and, when relevant, social) which set limits on application of modern physics and influence its development. For example, nuclear energy utilization may be studied in terms of the physics of fission, fusion, and plasmas, along with the technological and social factors affecting development of nuclear energy sources. Applications of physics in other sciences such as astrophysics and biology may also be included.

IPG323 (8123) Statistical Thermodynamics (u). Fall. Credit four hours. M W F 11:15. J. M. Blakely.

Quantum statistical basis for equilibrium thermodynamics, canonical and grand canonical ensembles, and partition functions. Laws of thermodynamics, concepts of temperature, entropy, free energy, etc. Differential thermodynamic relations. Quantum and classical ideal gases and para-magnetic systems, Fermi-Dirac, Bose-Einstein, and Maxwell-Boltzmann statistics. Introduction to systems of interacting particles. At the level of *Thermal Physics* by Kittel and *Statistical and Thermal Physics* by Reif.

IPG424 (8124) Statistical Physics (u). Spring. Credit four hours. M W F 11:15. R. V. Lovelace.

Elementary kinetic theory of gases in terms of the single-particle distribution function: transport processes involved in viscosity, heat conductivity, particle diffusion, and electrical resistivity; the Boltzmann equation and the H theorem. Fluctuations and irreversible processes: the master equation, the Langevin equation, the Fokker-Planck equation, and Brownian movement; electromagnetic noise and Nyquist's theorem; the Wiener-Khintchine relations; entropy production and the Onsager reciprocal relations.

IPA333 (8133) Mechanics of Particles and Solid Bodies (u). Fall. Credit four hours. Three lectures, one recitation. M W F 10:10. W. W. Webb.

Primarily for majors in engineering physics. Newton's laws; coordinate transformations; generalized coordinates and momenta, Lagrangian and Hamiltonian formulation; applications to oscillator, restrained motion, central forces, small vibrations of multiparticle systems, motion of rigid body.

IPA434 (8134) Continuum Physics (u). Spring. Credit four hours. Three lectures, one recitation. A. Kuckes.

Stress tensor; equation of reaction; Euler's equation; incompressible and compressible flow; strain tensor; elements of elasticity theory; elastic waves; viscous liquids and anelastic solids.

IPA355 (8155) Intermediate Electromagnetism (u). Fall. Credit four hours. Prerequisite: Physics BPS234 and BPS236, and coregistration in Mathematics BMA421 or consent of the instructor. T Th S 10:10. B. R. Kusse.

Topics include vector calculus, electrostatic and magnetostatic fields as solutions of boundary value problems, dielectric and magnetic media, mechanical and electric energy and pressure. Also, electric induction phenomena, skin effect, and the introduction of displacement current. Emphasis on the application of concepts to physical phenomena and engineering. At the level of *Lectures on Physics,* Vol. II, by Feynman, and *Foundations of Electromagnetic Theory* by Reitz and Milford.

IPA456 (8156) Intermediate Electrodynamics (u). Spring. Credit four hours. Prerequisite: IPA355, coregistration in Mathematics BMA422, or consent of instructor. T Th S 10:10. T. A. Cool.

Development of electromagnetic wave phenomena and radiation. Topics include transmission lines, waveguides, wave properties of dispersive media, radiation and scattering phenomena, reciprocity, physical optics, and special relativity. Emphasis is on concepts and their application to physical phenomena and engineering. At the level of *Lectures on Physics,* Vol. II, by Feynman, and *Classical Electromagnetic Radiation* by Marion.

IPG461 (8161) Introductory Quantum Mechanics (u). Spring. Credit four hours. Prerequisite: IPA333 or Physics BPS318; coregistration in Mathematics BMA422 and in IPA456 or Physics BPS326. Three lectures, one recitation. M W F 10:10, Th 2:30–4. M. S. Nelkin.

A first course in the systematic theory of quantum phenomena. Topics will include wave packets and the Schroedinger equation, illustrative solutions for the square well, harmonic oscillators and the hydrogen atom, the formal structure of quantum mechanics, angular momentum, spin, and the exclusion principle, perturbation theory, and an introduction to symmetries and to the quantization of the electromagnetic field. This course, which is similar in content to Physics BPS443, is made available in the spring semester to allow flexibility in scheduling. At the level of Chapters 4 through 9 of *Modern Physics and Quantum Mechanics* by Anderson.

IPB711 (8211) Principles of Diffraction (g). (Same as Materials Science and Engineering ITF706.) Fall. Credit three hours. B. W. Batterman.

Production of neutrons, X rays, absorption, scattering, Compton effect. Diffraction from periodic lattices, crystal symmetry, single crystal and powder techniques. Fourier methods, thermal vibration and scattering, diffraction from liquids and gases, introduction to dynamical diffraction of X rays and electrons, extinction phenomena, and perfect crystals. Selected experiments in diffraction.

IPB712 (8212) Selected Topics in Diffraction (g). (Same as Materials Science and Engineering ITF712.) Spring. Credit three hours. B. W. Batterman.

Dynamical diffraction: Ewald-von Laue theory of dynamical diffraction applied to X rays and electrons. Currently developing theory and application to defects in solids. Phenomena investigated via diffuse scattering: phonons, measurement of dispersion curves, frequency spectrum, Debye temperatures, vibrational amplitudes. Order-disorder phenomena: short and long-range order, Guinier-Preston zones. Selected topics of current interest related to x-ray, neutron, and electron diffraction, with contributions from other members of the faculty.

IPK753 (8252) Selected Topics in Fields Technically Related to Engineering Physics (g). Either term. Credit one hour. Primarily for candidates for the Master of Engineering (Engineering Physics) degree.

The student is expected to attend and participate in a minimum of fifteen scheduled University seminars and/or colloquia chosen in technical or scientific areas close to that of the student's chief interest. A brief summarizing report on each of these seminars is presented to the staff member overseeing the course. It is expected that the seminar material may be augmented by the student in his report by reference to and inclusion of related research reported in the literature and read by him.

[IPG761 (8261) Kinetic Theory (g). (Same as Electrical Engineering IEE781.) Spring, every other year. Credit three hours. Two lectures. Prerequisite: Physics BPS561, BPS562, or permission of instructor. R. L. Liboff. Not offered in 1973–74; will be offered spring term 1975.

Designed for students wishing a firm foundation in fluid dynamics, plasma-kinetic theory and nonequilibrium statistical mechanics. Brief review of classical dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analyses of the BBKGY sequence. Master equation, density matrix, Wigner distribution. Derivation of fluid dynamics. Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Klimontovich formulation. Kubo theory. Coarse graining and ergodic theory. At the level of *Introduction to the Theory of Kinetic Equations* by Liboff.]

IPB762 (8262) Physics of Solid Surfaces (g). (Same as Materials Science and Engineering ITG762). Spring. Credit three hours. A lecture course for graduate students and upperclassmen. T. N. Rhodin and J. M. Blakely.

Equilibrium thermodynamics and statistical mechanics of interfaces. Atomic structure of surfaces in equilibrium. Surface fields, dipoles, and defects in insulators. Electronic and vibrational properties of surfaces. Surface barriers and work functions, surface vibrational and electronic states. Kinetic processes at surfaces. Mass and charge transport. Condensation and evaporation processes. Experimental techniques. Materials drawn from research papers and various review articles in journals such as *Progress in Materials Science, Advances in Chemistry,* and *Solid State Physics.*

IPC201 (8301) Nuclear Energy and the Environment (u). Fall. Credit three hours. Two lectures and one two-hour recitation or laboratory each week. The level of presentation assumes knowledge of introductory physics, chemistry, and calculus, but previous knowledge of biology is not required. T Th 11:15. V. O. Kostroun.

Fundamentals of nuclear radiations and their measurement and interaction with matter, the natural radiation environment, and sources of man-made radioactivity (five weeks); radiation chemistry, radiation biology, somatic and genetic effects of nuclear radiation, movement of radioactive materials in the biosphere, and bases of radiation protection standards (five weeks); environmental effects of nuclear electricity generation and nuclear fuel mining, processing and waste storage, control of radiation hazards, and waste heat problems (four weeks).

IPC303 (8303) Introduction to Nuclear Science and Engineering (u). Spring. Credit three hours. Prerequisite: sophomore physics and mathematics. M W F 8. D. D. Clark.

An introductory course in low-energy nuclear physics and nuclear engineering for juniors and seniors other than those majoring in Engineering Physics. The objective is to acquaint students with low-energy nuclear physics and some of its practical applications. The following topics will be covered: elementary quantum mechanics; properties and structure of nuclei; radiations emitted by nuclei and their interaction with matter; nuclear reactions, with emphasis on fission and fusion processes; the neutron chain reaction; types and uses of nuclear radiations, such as neutron activation analysis and radioactive tracer analysis.

IPC609 (8309) Low-Energy Nuclear Physics (g). Fall. Credit four hours. Three lectures. Prerequisite: an introductory course in modern physics including quantum mechanics. Also open to qualified seniors. M W F 9. D. D. Clark.

The nuclear interaction. Properties of ground and excited states of nuclei; models of nuclear structure; alpha, beta, gamma radioactivity; low-energy nuclear reactions—resonant and nonresonant scattering, absorption, and fission. At the level of *Introduction to Nuclear Physics* by Enge.

IPC610 (8310) Nuclear Structure Physics (g). Spring. Credit three hours. Prerequisite: IPC609 or Physics BPS444 or equivalent. V. O. Kostroun.

Symmetry properties of nuclei, the collective model, basic reaction theory, compound and direct reactions, the optical model, charged particle reactions. At the level of *Physics of the Nucleus* by Preston.

IPC612 (8312) Nuclear Reactor Theory I (g). Fall. Credit four hours. Three lectures. Prerequisite: one year of advanced calculus and some familiarity with nuclear physics. Also open to qualified seniors. M W F 10:10. M. S. Nelkin.

A first course in the physical theory of fission reactors. The fission process and the essential properties of neutron interactions with matter are described. The theory of neutron diffusion, slowing down, and thermalization is developed. The theory is applied to calculations of criticality and neutron flux distribution in nuclear reactors. Attention is restricted to idealized configurations in order to illustrate the physical ideas involved. Nuclear reactor kinetics and neutron transport theory are introduced. At the level of *Nuclear Reactor Theory* by Lamarsh.

IPC613 (8313) Nuclear Reactor Theory II (g). Spring. Credit three hours. A continuation of IPC612, primarily intended for students planning research in nuclear reactor physics and engineering. Three lectures. Prerequisite: IPC612. Times to be arranged. K. B. Cady.

The Boltzmann linear transport equation, its adjoint, and their approximate solutions are developed and applied to the heterogeneous neutron chain reactor. The theories of fast fission effect, resonance escape, and thermal utilization are developed for heterogeneous reactors. The escape probability formulation of reactor lattices, the neutron importance function, perturbation theory, temperature coefficients of reactivity, and fission product poisoning are also treated. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner.

IPC633 (8333) Nuclear Reactor Engineering (g). Fall. Credit four hours. Prerequisite: introductory course in nuclear engineering. Also open to qualified seniors. Times to be arranged. K. B. Cady.

A selected set of topics representing the fundamentals of nuclear reactor engineering; energy conversion and power plant thermodynamics, reactor plant fluid flow and heat transfer, thermal stresses, radiation protection and shielding, routine and accidental discharge of radionuclides from nuclear reactors, and nuclear fuel cycles. At the level of *Nuclear Reactor Engineering* by Glasstone and Sesonske.

IPC634 (8334) Nuclear Engineering Design Seminar (g). Spring. Credit four hours. Prerequisite: IPC633. Times to be arranged. K. B. Cady.

A group design study of a selected nuclear reactor system. Emphasis is on safety, siting, and radiation protection in the design of nuclear power systems.

IPC636 (8336) Seminar on Thermonuclear Fusion Reactors (g). Spring. Credit three hours. Prerequisite: a basic course in plasma physics or nuclear reactor engineering, or consent of the instructor. Also open to qualified seniors. Times to be arranged. H. H. Fleischmann.

The present state of the technological and engineering problems expected in the design and construction of thermonuclear fusion reactors will be analyzed. Topics will include basic reactor containment schemes, materials development, mechanical and heat transfer problems, refueling, radiation and safety hazards, superconducting magnets, energy conversion, and economics.

IPC651 (8351) Nuclear Measurements Laboratory (g). Spring. Credit four hours. Two 2½-hour afternoon periods. Prerequisite: some knowledge of nuclear physics. Also open to qualified seniors. Th F 2–4:30. D. D. Clark.

Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Twenty different experiments are available in the fields of nuclear and reactor physics and radiation protection. Among these are experiments on emission and absorption of radiation, radiation detectors and nuclear electronic circuits, interactions of neutrons with matter (absorption, scattering, moderation, and diffusion), activation analysis and radiochemistry, and properties of a subcritical assembly. Many of the experiments use the TRIGA Reactor. The student is expected to perform eight to ten experiments, selected to meet his needs. Some stress is placed on independent work by the student. At the level of *Nuclear Radiation Detection* by Price.

IPC652 (8352) Advanced Nuclear and Reactor Laboratory (g). Spring. Credit three hours. Two 2½-hour afternoon periods. Prerequisite: IPC651 and IPC609 or IPC612. Th F 2–4:30. Offered on independent study basis or, if sufficient demand, as a formal course.

Laboratory experiments and experimental methods in nuclear physics and reactor physics. Ten different experiments are available, among them ones using the Zero Power Reactor critical facility.

IPD401 (8501) Physics of Atomic and Molecular Processes (u,g). Fall. Credit three hours. Prerequisite: IPG461, Physics BPS443, or consent of instructor. H. H. Fleischmann.

An introduction to the basics of contemporary problems in the physics of atomic and molecular processes, including atomic structure, chemical bonding, radiation resonance processes, and elastic and inelastic collisions. At the level of *Quantum Mechanics* by Blokhintsev, and the final chapters of *Introduction to Quantum Mechanics* by Park.

IPG705 (8505) Topics in Statistical Physics (g). Fall. Credit three hours. Prerequisite: IPG424 or Physics BPS562 or Chemistry BCH796. Coregistration in Physics BPS653 recommended.

Selected topics of current research interest in statistical physics.

IPE606 (8506) Introduction to Plasma Physics (u,g). (Same as Electrical Engineering IEE681). Fall. Credit three hours. Three lectures. Prerequisite: IPA355, IPA456, or equivalent. Open to fourth-year students at discretion of instructor. R. N. Sudan.

Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles, and microscopic instabilities; test particle in a plasma; elementary applications. At the level of *Elementary Plasma Physics* by Longmire.

IPE607 (8507) Advanced Plasma Physics (u,g). (Same as Electrical Engineering IEE682). Spring. Credit three hours. Three lectures. Prerequisite: IPE606. R. N. Sudan.

Boltzmann and Vlasov equations; moments of kinetic equation, Chew-Goldberger-Low theory, waves in hot plasmas, Landau damping, instabilities due to anisotropies in velocity space, gradients in magnetic field, temperature and density, effects of collisions and Fokker-Planck terms; high-frequency conductivity and fluctuations, quasi-linear theory; nonlinear wave interaction, weak turbulence and turbulent diffusion.

IPD609 (8509) Molecular Energy Transfer (g). Fall. Credit three hours. T. A. Cool.

Fundamentals of energy transfer by molecular collisions in gases. Energy transfer mechanisms in molecular and chemical lasers. Intermolecular potential, dispersion forces, multipole moment interactions, repulsive forces. Processes for interconversion of vibration, rotation, and translational energy. Perturbation methods in vibrational energy transfer. Survey of experimental data and techniques for measurement of rates of energy transfer: shock tubes, laser-induced fluorescence, laser schlieren, optic acoustic effect. Transfer chemical lasers, vibration-vibration pumping, dissociation lasers. Laser diagnostics of chemically reacting systems.

IPB612 (8512) Electron Microscopy and Diffraction (g). Spring. Credit three hours. J. Silcox.

A discussion of selected topics in the areas of electron microscopy and diffraction, with the major emphasis on microscopy. Probable topics include: elastic and inelastic electron scattering from atoms, molecules, and aggregates of matter; nature of image formation—amplitude, phase, and diffraction contrast; resolution; magnetic domain structure as a phase grating and atomic planes as a diffraction grating; kinematical 2-beam, and n-beam dynamical theories of perfect crystals; phenomenological treatment of absorption; extension to imperfect crystals—diffraction contrast from defects such as dislocations, stacking faults, coherent and incoherent precipitates; discussion of inelastic scattering; instrumental and fundamental limitations on source properties and image formation capabilities and reasons for current research activities devoted to extending the capabilities.

[IPF601 (8601) Photosynthesis (u,g). (Same as Biological Sciences OBE545). Fall. Credit two hours. Prerequisite: Chemistry BCH104 or BCH108, Mathematics BMA108, BMA111, or BMA191, and Physics BPS102, BPS108, or BPS214, or consent of instructor. Past or current registration in IPF605 is recommended. R. K. Clayton. Not offered in 1973–74 or 1974–75.

A detailed study of the process by which plants use light in order to grow, emphasizing physical and physico-chemical aspects of the problem.]

[IPF603 (8603) General Photobiology (u,g). (Same as Biological Sciences OBE547). Fall. Credit two hours. Prerequisite: Chemistry BCH104 or BCH108, Mathematics BMA108, BMA111, or BMA191, and Physics BPS102, BPS108, or BPS214, or consent of instructor. Lectures, T Th 10:10. R. K. Clayton. Not offered in 1973–74.

A study of the major interactions between light and living matter as encountered in photosynthesis, vision, regulation of physiology and development, bioluminescence, and damage by ultraviolet and visible light.]

[IPF605 (8605) Optics in Biology (u,g). (Same as Biological Sciences OBA405.) Fall. Credit two hours. Prerequisite: Chemistry BCH104 or BCH108, Mathematics BMA108, BMA111, or BMA191, and Physics BPS102, BPS108, or BPS214, or consent of instructor. R. K. Clayton. Not offered in 1973–74.

Lectures, problems, demonstrations, and laboratory experience in applications of optics to biology. Topics will include geometrical optics as applied to illumination systems, methods for studying biological effects of light, and analytical uses of optical absorption and fluorescence.]

IPF306 (8606) The Physics of Life (u). Spring. Credit three hours. Prerequisite: Physics BPS101 or BPS112 and Chemistry BCH104 or BCH108. Two lectures. T Th 8:30–9:55. A. Lewis.

This course deals with the physics of life within the unity and interdependence of living matter. It aims at developing in the student an appreciation for the applicability of physical principles in understanding the processes which underlie our life. Topics to be covered are photosynthesis as elucidated by molecular spectroscopy, protein structures and reactivity as exemplified by hemoglobin (the plant-animal interface), membrane function in terms of metabolism (a parallel process to respiration), reproduction of the organism and nucleic acids, and perception by the organism.

Chemical Engineering

IHE101 (5041) Nonresident Lectures (u). Fall. One lecture. K. B. Bischoff and C. C. Winding.

Given by lecturers invited from industry and from selected departments of the University for the purpose of assisting students in their transition from college to industrial life.

[IHE102 (5061) Seminar on the Engineer and Society (u,g). Fall. Credit one hour. Not offered in 1973–74.

Review of major social changes caused by science and technology; discussion of current social challenges to the engineer, with particular emphasis on the chemical process industry.]

IHE110 (5111) Mass and Energy Balances (u). Either term. Credit three hours. Prerequisite: one year of freshman chemistry or consent of instructor. R. G. Thorpe.

Content is the same as for IHE111, but this course uses *only self-paced audiovisual instruction at the convenience of the student.* A minimum of seventy clock hours of audiovisual instruction is required to master the subject matter. Student performance is evaluated by nine tests, two preliminary examinations, and a final examination. Superior students may earn exemption from the final examination.

IHE111 (5101) Mass and Energy Balance (u). Either term. Credit three hours. Three lectures, one computing session. Prerequisite: one year of freshman chemistry or consent of instructor. R. G. Thorpe.

Engineering problems involving material and energy balances. Batch and continuous reactive systems in the steady and unsteady states. Humidification processes. (*See also* IHE110.)

IHE311 (5102) Equilibria and Staged Operations (u). Fall. Credit three hours. Three lectures, one computing session. R. G. Thorpe.

Phase equilibria and phase diagrams. The equilibrium stage; mathematical description of single and multistage operations; analytical and graphical solutions.

IHE312 (5103) Chemical Engineering Thermodynamics (u). Spring. Credit three hours. Three lectures. Prerequisite: IHE311, Chemistry BCH287, BCH288. R. L. Von Berg.

A study of the first and second laws with application to batch and flow processes. Physical and thermodynamics properties; availability; free energy; chemical equilibrium. Applications to gas compression, refrigeration, power generation, adiabatic reactors, and chemical process development.

IHE321 (5257) Materials (u). Fall. Credit five hours. Three lectures, two laboratories. G. G. Cocks.

An introductory presentation of the nature, production, properties, applications, and behavior under service conditions of materials. Laboratory includes elements of chemical microscopy, crystallography, and the microscopic characterization of materials.

IHE410 (5106) Reaction Kinetics and Reactor Design (u,g). Spring. Credit three hours. Three lectures. Prerequisite: IHE430.

A study of chemical reaction kinetics and principles of reactor design for chemical processes.

IHE430 (5304) Introduction to Rate Processes (u). Spring. Credit three hours. Three lectures, one computing session. Prerequisite: IHE311. J. F. Stevenson.

An introduction to fluid mechanics, heat and mass transfer.

IHE431 (5305) Analysis of Separation Processes (u). Fall. Credit three hours. Three lectures, one computing session. Prerequisite: IHE430, familiarity with CUPL, the Cornell computing language. G. F. Scheele.

Analysis of separation processes involving phase equilibria and rate of mass transfer; extensive use of the digital computer. Phase equilibria; binary, multicomponent, and extractive distillation; liquid-liquid extraction; gas absorption.

IHE432 (5353) Unit Operations Laboratory (u). Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: IHE430. J. L. Anderson, J. C. Smith, and C. C. Winding.

Laboratory experiments in fluid dynamics, heat transfer, and mass transfer. Correlation and interpretation of data. Technical report writing.

IHE433 (5354) Project Laboratory (u). Fall and spring. Credit three hours. Prerequisite: IHE432.

Special laboratory projects involving bench-scale or pilot-plant equipment.

IHE461 (5623) Chemical Process Evaluation (u). Fall. Credit four hours. H. F. Wiegandt.

A study of the important chemical processes.

IHE462 (5624) Chemical Process Synthesis (u). Spring. Credit four hours. J. C. Smith and C. C. Winding.

A consideration of process and economic alternatives in selected chemical processes, along with technological assessment.

IHE561 (5621) Process Design and Economics (g). Fall. Credit six hours. Prerequisite: IHE312, IHE430, IHE431 or equivalent. R. York.

Methods for estimating capital and operating costs. Performance, selection, design, and cost of process equipment. Process development and design. Market research and survey.

IHE562 (5622) Process and Plant Design (g). Spring. Credit six hours. Prerequisite: IHE561. Staff.

Process design, including reactors, process equipment, and separating systems. Layout and model of process units. Plant location, design, and layout. Cost estimates and project evaluation.

IHE611 (5161) Phase Equilibria (u,g). Fall. Credit three hours. Three lectures. Prerequisite: physical chemistry. R. G. Thorpe.

A detailed study of the pressure-temperature-composition relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Prediction of phase data.

IHE621 (5741) Petroleum Refining (g). Fall. Credit three hours. Three lectures. Prerequisite: IHE430. H. F. Wiegandt.

A critical analysis of the processes employed in petroleum refining.

IHE622 (5731) Industrial Waste Engineering (u,g). (Same as Agricultural Engineering OAE676 and Civil and Environmental Engineering IIE631.) Spring. Credit three hours. Primarily a graduate course, but open to upperclassmen in Chemical, Agricultural, or Civil and Environmental Engineering, or in the College Program with a major from these fields.

Offered jointly with Agricultural Engineering and Civil and Environmental Engineering as an integrated presentation. The first third is concerned with legal aspects, assimilatory capacity of receiving waters, joint industrial-municipal collection of wastes, and sewerage service charges. The second part covers waste sampling and analysis, treatment processes, waste-reduction possibilities, water quality and quantity, water reuse and recovery, and costs. The final third includes discussions of specific industrial operations and selected case studies of industrial waste treatment. A study, in depth, of a particular waste problem is required of all students.

IHE623 (5790) Consumer Products Engineering (u,g). Fall. Credit three hours. Two lectures, one computing session. Open to qualified seniors and graduate students in engineering. J. E. Hedrick.

The organization and the interrelated departmental functions for the development of new consumer products. Case studies are drawn from industry to describe the special problems and situations encountered. The role of scientists and engineers in the consumer product industries is stressed.

IHE624 (5635) Marketing of Chemical Products (g). Fall. Credit three hours. Three lectures. Prerequisite: IHE561. J. E. Hedrick.

Examination of marketing activities, organizations, and costs in the distribution of chemicals. Chemical prices. A market research project is required.

IHE625 (5636) Economics of the Chemical Enterprise (g). Spring. Credit three hours. Three lectures. Prerequisite: IHE561. J. E. Hedrick.

Research economics; feasibility studies; information sources; venture analysis; planning.

IHE626 (5746) Case Studies in the Commercial Development of Chemical Products (g). Spring. Credit three hours. Three lectures. Prerequisite or parallel: IHE562. J. E. Hedrick.

Detailed analysis of specific cases involving the development of new chemical products. Particular emphasis is given to planning activities, research justification, and market forecasting. Profitability calculations and projections are required.

IHE627 (5760) Nuclear and Reactor Engineering (g). Spring. Credit two hours. Two lectures. Prerequisite: consent of instructor. R. L. Von Berg.

Fuel processing and isotope damage; biological effects and hazards; shielding; radiation chemistry.

[IHE628 (5641) Inventions, Patents, and Trade Secrets (u,g). Fall. Credit three hours. Not offered in 1973–74.

Protection of inventions and trade secrets. Statutory and other legal requirements for patentability of inventions. Evaluation of patents. Role and management of patents in planning growth and expansion into new product lines.]

[IHE629 (5642) Development Economics (g). Spring. Credit three hours. Prerequisite: IHE561, IHE562, IHE628. Not offered in 1973–74.

Planning, evaluation, and management of development activities in the process industries as related to research, processing, new products, markets, and long-range growth.]

IHE630 (5312) New Separation Techniques (u,g). Fall. Credit three hours. Three lectures.

Lectures, problems, and demonstrations of new or less common separation techniques such as chromatography; ion exchange, electrophoresis, and membrane operations; analysis, design, and scale-up.

IHE631 (5609) Mixing and Mechanical Separations (g). Fall. Credit three hours. Three lectures. Prerequisite: IHE430 or consent of instructor. J. C. Smith.

Principles of mixing of gases, liquids, and solids; agitation, solid suspension; gas dispersion and chemical reaction; filtration; sedimentation; special mechanical separations.

IHE640 (5742) Polymeric Materials (u,g). Fall. Credit three hours. Three lectures. F. Rodriguez.

Chemistry and physics of the formation and characterization of polymers. The engineering applications of polymers as plastics, fibers, rubbers, and coatings.

IHE641 (5743) Properties of Polymer Materials (g). Spring. Credit one to three hours. Three lectures. Prerequisite: IHE640. F. Rodriguez and J. F. Stevenson.

Polymer fluid dynamics and constitutive equations for viscoelastic materials. Special topics in polymeric materials.

IHE642 (5752) Polymeric Materials Laboratory (g). Fall. Credit two or three hours. One or two laboratories. Prerequisite: IHE640. F. Rodriguez.

Experiments in the formation, characterization, fabrication, and testing of polymers.

IHE643 (5770) Engineering Analysis of Physiological Systems (u,g). Spring. Credit three hours. K. B. Bischoff.

Engineering analysis and mathematical description of flow, transport phenomena, and chemical reactions involved in physiological system function. Cell and body fluid properties, the circulatory system and blood flow, renal system models, transport of drugs and other solutes, artificial organ design.

IHE644 (5748) Fermentation Engineering (u,g). Fall. Credit three hours. Two lectures, one recitation. Prerequisite or parallel: Chemistry BCH288 and any course in microbiology. R. K. Finn.

An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

IHE645 (5749) Industrial Microorganisms (u,g). Spring. Credit two hours. Prerequisite: organic chemistry and physical chemistry. R. K. Finn.

A brief introductory course in microbiology for students with a good background in chemistry.

IHE646 (5903) Seminar in Biochemical Engineering (g). Spring. Credit one hour.

Advanced topics in the engineering applications of biophysics and biochemistry. Discussion of current research in the field.

IHE647 (5761) Topics in Bioengineering (g). Spring. Credit two hours. Two lectures. Prerequisite: IHE644 or consent of instructor.

Analysis of transport phenomena, reaction kinetics, process dynamics and control, and optimization in biological systems. Topics include the dynamics of cell and virus population growth and facilitated transport in membranes.

IHE651 (5510) Numerical Methods in Chemical Engineering I (g). Fall. Credit three hours. Two lectures, one computing session. J. L. Anderson.

Application of computer methods to solution of complex chemical engineering problems. Emphasis on applications of numerical analysis and optimization of nonlinear systems.

[**IHE652 (5512) Numerical Methods in Chemical Engineering II (g).** Spring. Credit three hours. Two lectures, one computing session. Not offered in 1973–74.

Application of computer methods to solution of complex chemical engineering problems. Linear programming and simulation and design of chemical processes.]

IHE653 (5780) Statistical Applications in Process Development and Design (u,g). Spring. Credit three hours. Three lectures. J. C. Smith and K. B. Bischoff.

Applications of statistical methods in interpreting and correlating laboratory and pilot-plant data; quality control in process operations; designing experiments; allowing for uncertainty in design. Emphasis on methods useful in process development and plant design.

IHE671 (5717) Process Control (g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IHE430.

Dynamic response of processes and control instruments. Use of frequency response analysis. Laplace transforms and electronic analogs to predict the behavior of feedback control systems.

IHE672 (5750) Applied Surface Chemistry (u,g). Fall. Credit three hours. J. L. Anderson and R. E. Baier.

Aspects of surface chemistry and physics which have definite applications. Interactions at gas/liquid, solid/liquid, and solid/gas phase boundaries are described with emphasis on practical measures of their relative importance. Special attention is given the surface-energy-related parameter of "critical surface tension" for solids and its correlation with friction and wear, wetting, spreading and adhesion, and biological phenomena.

IHE680 (5851) Chemical Microscopy (u,g). Spring. Credit three hours. One lecture, two laboratories. Prerequisite or parallel: physical chemistry (e.g., Chemistry BCH287–288 or BCH389–390) and Physics BPS233–234, or special permission.

Microscopical examination of chemical and technical materials, processes, and products. The optics of the microscope, measurements, particle size determination, analyses of mixtures, optical crystallography, crystallization, phase changes, and colloidal phenomena.

IHE681 (5857) Electron Microscopy (g). Spring. Credit three hours. One lecture, two laboratories. Prerequisite: IHE680 or special permission. G. G. Cocks.

An introductory course in electron microscopy. The optics of the microscope, the operation and care of the microscope, methods of specimen preparation, and the interpretation of microscopical images.

IHE682 (5859) Advanced Chemical Microscopy (g). Offered on demand either term. Credit variable. Prerequisite: IHE680 and special permission. G. G. Cocks.

Laboratory practice in special methods and special applications of chemical microscopy.

IHE692, IHE693, IHE694 (5952, 5953, 5954) Research Project (g). Fall and spring. Credit three hours; additional credit by special permission. Prerequisite: IHE430.

Research on an original problem in chemical engineering.

IHE695, IHE696 (5955, 5956) Special Projects in Chemical Engineering (g). Either term. Credit variable.

Research or studies on special problems in chemical engineering.

IHE711 (5105) Advanced Chemical Engineering Thermodynamics (g). Fall. Credit three hours. Three lectures. Prerequisite: IHE312 or equivalent. R. L. Von Berg.

Application of general thermodynamic methods to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties; chemical and phase equilibrium.

[**IHE712 (5107) Reactor Design (g).** Spring. Credit three hours. Not offered in 1973–74.

Effects of heat transfer, diffusion, and nonideal flow on reactor performance. Optimum design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization.]

IHE713 (5109) Advanced Chemical Engineering Kinetics (g). Spring. Credit three hours. Three lectures. Prerequisite: IHE410 or equivalent. K. B. Bischoff.

Advanced treatment of applications of chemical kinetics to reactor design.

[**IHE714 (5508) Diffusion in Membranes and Porous Solids (g).** Spring. Credit two hours. Not offered in 1973–74.

Theories for diffusion of gases and liquids in porous solids, porous membranes, and dense membranes. Problems in analysis and correlation of experimental results.

IHE731 (5505) Advanced Transport Phenomena (g). Spring. Credit four hours. G. F. Scheele.

An integrated treatment of momentum, mass and heat transfer. Molecular transport; the equations of change; viscous laminar flow of Newtonian and non-Newtonian fluids; perfect fluid theory; boundary layer theory; unsteady-state transfer; penetration theory; models of mass and heat transfer; flow stability; turbulent transport; simultaneous heat and mass transfer; applications to industrial operations.

IHE751 (5501) Methods of Chemical Engineering Analysis (g). Fall. Credit three hours. May be taken by undergraduates with the permission of the instructor. K. B. Bischoff.

Methods of mathematical analysis of direct applicability in thermodynamics, transport phenomena, and chemical reactor design.

IHE790 (5900) Seminar (g). Fall and spring. Credit one hour.

General chemical engineering seminar required of all graduate students majoring in the field of chemical engineering.

IHE891, IHE892, IHE893 Thesis Research (g). Either term.

Thesis research for the Master of Science degree in chemical engineering.

IHE991, IHE992, IHE993, IHE994, IHE995. Thesis Research (g). Either term.

Thesis research for the Ph.D. degree in chemical engineering.

Civil and Environmental Engineering

Environment Sensing, Measurement, and Evaluation

IIA153 (2453) Principles of Navigation (u). Fall. Credit four hours. Three lectures, discussion period, and project work. G. B. Lyon.

Coordinate systems, chart projections, navigational aids, instruments, compass observations, tides and currents, sounding. Celestial navigation: time, spherical trigonometry, motion of the stars and sun, star identification, position fixing, use of Nautical Almanac. Electronic navigation.

IIA380 (2480) Engineering Surveying and Evaluation (u). Fall. Credit three hours. Two lectures, one laboratory. Intended for juniors as an introductory course. Staff.

Surveying: basic principles of geometric measurements, including errors and adjustment; modern surveying instruments and procedures for measuring and laying out angles, distances, areas, and volumes; use of coordinate systems and modern mapping methods for the acquisition and display of earth resources data. Evaluation: significance of the several components of the physical environment in engineering projects; assessment of information about these components from maps, airphotos, and ground data; land inventory systems.

IIA681 (2481) Photogrammetry (u,g). Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: permission of instructor. A. J. McNair.

Principles of terrestrial, aerial, and space photogrammetry; geometry of a photograph, tilt and relief displacements, parallax distortions, control requirements, flight planning. Stereo plotting: relative and absolute orientation, use of Bausch and Lomb Balplex, Wild A-9 Autograph, and Zeiss stereometric camera, including Terragraph plotter. Geometry of remote sensors.

IIA682 (2482) Analytic Aerotriangulation (u,g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IIA681. A. J. McNair.

Coplanarity and colinearity mathematical equations for performing spatial solutions for resection and orientation for single photo, stereo pair, triplet, strip, sub-block, and block coverages of various types of surfaces for which positioning is sought. Stereogram assemblage and coordinate transformation of strip and block coordinates. Solutions of large rectangular matrices in photogrammetry.

IIA683 (2483) Geodesy (u,g). Spring. Credit three hours. Three lectures. Prerequisite: permission of instructor. A. J. McNair.

The future of the earth and the precise determination of position on or near the earth's surface. Fundamentals of geometric geodesy, geodetic astronomy, physical geodesy, satellite geodesy, and map projections.

IIA685 (2485) Physical Environment Evaluation (u,g). Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: permission of instructor. T. Liang and D. J. Belcher.

A study of physical environment and resources factors affecting engineering and planning decisions and methods of evaluating these factors. Physical factors include the climate, soil and rock conditions, and water resources in different parts of the world. Evaluation methods include field reconnaissance, interpretation of meteorological, topographic, geological, and soil maps, and use of aerial photography, engineering data, and subsurface exploration records. Display and presentation.

IIA686 (2486) Advanced Physical Environment Evaluation (u,g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IIA685 or IIA687 or permission of instructor. T. Liang and D. J. Belcher.

A study of physical environment and resources by use of aerial photography and other remote sensing methods. Conventional photography, sequential photography, multiple spectral photography, space photography, and infrared thermal and radar imagery. Evaluation of environment is directed to the planning of engineering and development projects in general, with some emphasis on those related to special climatic regions such as arctic, tropical, humid, and arid regions.

IIA687 (2487) Analyses and Interpretation of Aerial Photographs (u,g). Fall and spring. Credit three hours. Two lectures, one laboratory. Prerequisite: permission of instructor. Preregistration required. The student is expected to pay the cost of field trips, and aerial photographs for use in a term project—approximately $15. D. J. Belcher and T. Liang.

Methods of identification of a broad spectrum of soils, rocks, and drainage conditions; the significance of vegetative and cultural patterns of the world. Natural resources inventories and specific fields of application are emphasized.

IIA688 (2488) Advanced Interpretation of Aerial Photographs (u,g). Fall and spring. Credit three hours. Prerequisite: IIA687 or permission of instructor. D. J. Belcher and T. Liang.

Lectures and team projects in laboratory and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water, and civil engineering projects.

IIA689 (2489) Remote Sensing (u,g). Spring. Credit three hours. Two lectures, one laboratory. Staff and guest lecturers.

Sensing and sensors in the electromagnetic spectrum, with special emphasis on thermal and radar sensing. Project planning, imagery geometry, data acquisition, manipulation, and display. Supporting ground investigation. Analysis and interpretation of images.

IIA691 (2491) Design Project (u,g). On demand. Credit one to six hours. Staff.

Design problems, frequently associated with the Master of Engineering program.

IIA692 (2492) Research (g). On demand. Credit one to six hours. Staff.

For students who wish to study one particular area in depth. The work may take the form of a laboratory investigation, field study, theoretical analysis, or the development of design procedures.

IIA693 (2493) Seminar (u,g). On demand. Credit one hour. Staff.

Presentation and discussion of technical papers and current research in the general field or one of its specialized fields.

IIA694 (2494) Special Topics (u,g). On demand. Credit one to six hours. Staff.

Supervised study in small groups on one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

IIA696 (2496) Seminar in Remote Sensing (u,g). Credit one hour. Staff and guest lecturers.

Presentation and discussion of current research and development in remote sensing. Lectures by Cornell staff members and invited specialists from government and industry.

Technology Assessment and Economics

IIB201 (2201) Economic Analysis of the Private Sector (Microeconomics) (u). (Same as Economics 307.) Fall. Credit four hours. Prerequisite: one year of college-level mathematics. Acceptable as a liberal elective for undergraduates in engineering. May be taken for credit in addition to Economics 102, although Economics 102 is not a prerequisite. R. E. Schuler.

Considers the economic behavior of individual households and firms; how individual agents combine under different market structures, including competitive markets, monopoly, and monopsony; and concludes with the theory of distribution and general equilibrium. Most topics will receive both graphical and mathematical treatment. The course is designed to provide students with adequate preparation to take any advanced-level economics course for which Economics 311 is a prerequisite.

IIB202 (2202) Economic Analysis of Government (u). (Same as Economics 308). Spring. Credit four hours. May be taken for credit in addition to Economics 101, although Economics 101 is not a prerequisite. Prerequisite: one year of college-level mathematics and IIB201; or Economics 311. R. E. Schuler.

A continuation of IIB201. First half: consideration of the welfare implications of various forms of economic organization and the rationale for government intervention in the microeconomy. The theory underlying investment in government projects and environmental programs will be studied. Second half: national economic constraints and aggregate behavior (macroeconomics) together with the impact of government activity on these aggregates. Mathematical as well as graphical tools of analysis are used.

IIB203 (2205) Social Implications of Technology (u,g). Fall. Credit three hours. S-U grades optional. Open to all Cornell students beyond the freshman year. Acceptable as a liberal elective for undergraduate students in engineering. Students from outside the College of Engineering are invited to take this course. P. L. Bereano.

Some of the issues pertaining to the development, implementation, and assessment of technology. The social, political, and economic aspects of current problems which have important technological components. The technical background will be developed to the extent necessary for an intelligent consideration of policy alternatives. Students will be required to do extensive reading and may be required to participate in case studies or write a term paper.

Fluid Mechanics and Hydrology

IIC301 (2301) Fluid Mechanics (u). Credit three hours. Three lecture-recitations. W. H. Brutsaert.

Fluid properties, hydrostatics, the basic equations of fluid flow, potential flow, dimensional analysis, flow in conduits, open channel flow.

IIC302 (2302) Hydraulic Engineering (u). Spring. Credit three hours. Two recitations, one laboratory. Prerequisite: IIC301. J. A. Liggett.

Free surface and pipe flow, fluid meters and measuring devices, hydraulic machinery, unsteady flow, waste heat discharges into lakes and rivers, applications of fluid mechanics. Laboratory will include a number of experiments in fluid mechanics and hydraulic engineering.

IIC609 (2309) Descriptive Hydrology (u,g). Spring. Credit two hours. Intended for non-engineering majors. Prerequisite: permission of instructor. W. H. Brutsaert.

Introduction to hydrology as a description of the hydrologic cycle and the role of water in the natural environment. Topics include precipitation, infiltration, evaporation, ground water, surface runoff, floods, and droughts.

IIC612 (2312) Experimental and Numerical Methods in Fluid Mechanics (u,g). Offered on demand. Credit two hours. Prerequisite: IIC302 or permission of instructor. Staff.

Primarily laboratory, for undergraduates and graduates; may be repeated for credit upon permission of the instructor. Emphasis is on planning and conducting laboratory and field experiments and numerical computation.

IIC615 (2315) Advanced Fluid Mechanics I (g). Fall. Credit three hours. Three recitations. Prerequisite: IIC301. J. A. Liggett.

Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy from a rigorous point of view. Similitude and modeling potential flow including circulation, vorticity, conformal mapping, and hodograph methods.

[**IIC617 (2317) Free-Surface Flow (u,g).** Spring. Credit three hours. Three recitations. Prerequisite: IIC615 or IIC618, or permission of instructor. J. A. Liggett. Not offered in 1973–74.

The formulation of the free-surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels.]

IIC618 (2318) Dynamic Oceanography (u,g). Fall. Credit three hours. Prerequisite: elementary fluid mechanics. J. A. Liggett.

The statics and dynamics of oceans and lakes. Currents in homogeneous and stratified bodies of water. Tides, seiches, waves, and tsunamis. Turbulence and diffusion.

IIC620 (2320) Analytical Hydrology (u,g). Fall. Credit three hours. Prerequisite: IIC301 or equivalent. W. H. Brutsaert.

Physical and statistical analysis related to hydrologic processes. Hydrometeorology and evaporation. Infiltration and base flow. Surface runoff and channel routing. Linear and nonlinear hydrologic systems analysis. Storage routing and unit hydrograph theory.

IIC691 (2391) Project (u,g). Offered on demand. Hours and credit variable. Staff.

The student may elect a design problem or undertake the design and construction of special equipment in the fields of fluid mechanics, hydraulic engineering, or hydrology.

IIC693 (2393) Hydraulics Seminar (u,g). Spring. Credit one hour. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. Staff.

Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

IIC694 (2394) Special Topics in Hydraulics (u,g). On demand. Hours and credit variable. Staff.

Special topics in fluid mechanics, hydraulic engineering, or hydrology.

IIC716 (2316) Advanced Fluid Mechanics II (g). Spring. Credit three hours. Three recitations. Prerequisite: IIC615. J. A. Liggett.

Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics.

IIC721 (2321) Flow in Porous Media (g). Spring. Credit three hours. Prerequisite: IIC301; IIC615 also recommended. W. H. Brutsaert.

Fluid mechanics of flow through porous solids. The general equations of single phase and multiphase flow and the methods of solving the differential form of these equations. Hydraulics of wells, infiltration, ground water recharge, and other steady state and transient seepage problems in fully and partially saturated materials.

IIC792 (2392) Research in Hydraulics (g). Offered on demand. Hours and credit variable. Staff.

The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either of an experimental or theoretical nature. Results should be submitted to the instructor in charge in the form of a research report.

Soil Mechanics and Foundations

IID301 (2401) Elements of Soil Mechanics (u). Spring. Credit three hours. Two lectures, one laboratory. D. A. Sangrey.

Soil properties; chemical nature; particle size distribution; Atterberg limits; permeability; principle of effective stress; compressibility; shear strength; the consolidation process. Introduction to bearing capacity; earth pressure; slope stability; settlement; seepage and the solution of practical problems. Laboratory tests for the measurement of soil properties.

IID606 (2406) Engineering of Foundations and Earth Retaining Structures (u,g). Fall. Credit three hours. Two lectures, one two-hour period. Prerequisite: IID301. J. N. Kay.

Mechanics and development of earth pressure in relation to soil properties and deformation. Design of retaining walls and bulkheads. Principles of bearing capacity, stress and distribution, and settlement. Design of shallow and deep foundations, footing, raft, caisson, and pile foundations. Problems of construction and stability of excavations. Influence of groundwater flow on walls, foundations, and excavations.

IID610 (2410) Engineering Properties of Soils (u,g). Fall. Credit three hours. Three lectures. Prerequisite: IID301. Undergraduates must have a grade of B or better in IID301 or permission of instructor. D. A. Sangrey.

Natural environments in which soils are formed; the chemical and physical nature of soils. Principle of effective stress; shear strength and compressibility of natural geotechnical materials. Sensitivity, partial saturation, organic and frozen materials, anisotropy. Primary and secondary consolidation. Soil properties influencing permeability.

IID616 (2416) Slope Stability: Earth and Rockfill Dams (u,g). Spring. Credit three hours. Two lectures and one two-hour period. Prerequisite: IID301. D. A. Sangrey.

Principles of stability for earth and rock slopes; effects of pore water pressure; short and long term stability; problems of drawdown; analysis of landslides and dam stability; principles of earth and rock-fill dam design; internal pore water pressures and drainage; filters; relief wells; foundation problems; grouting; cut-offs; control and instrumentation.

[IID631 (2431) Pavement Design and Construction (u,g). On demand. Credit three hours. Two lectures, one laboratory. Prerequisite: IID301 or permission of instructor. Not offered in 1973–74.

Part I: subgrade evaluation; compaction; drainage and frost action; stabilization. Part II: aggregates; bituminous materials; evaluation of flexible pavement components; design and construction of flexible pavement structure. Part III: design and construction of rigid pavements.]

IID632 (2432) Highway Engineering (u,g). (Same as Agricultural Engineering OAE491.) Offered upon sufficient demand, usually in the fall term. Credit three hours. Prerequisite: consent of instructor. Principally directed study and individual or team investigations with one 2½-hour session per week, to be arranged.

Emphasis is on secondary roads in study of: economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

IID645 (2445) Field Practice in Geotechnical Engineering (u,g). Fall and spring. Credit one hour each term. Field studies are conducted as two-day trips allocated to appropriate weekends in each term. (The student is expected to pay transportation and related costs, amounting to approximately $85.) Prerequisite: IID301 or permission of instructor. Staff.

Designed to provide experience with field conditions in important project environments within reach of the campus, including construction scenes in New York and central Pennsylvania. Reports on various sites are required. Field testing and sampling; resistivity and seismic probing of soils and bedrock; soil moisture and density measurements using nuclear equipment. Engineering construction practices and site evaluation related to landslides, bedrock, drainage, and unstable soils. The influence of rock types, ground water, and soil materials on existing structures; appropriate design procedures applied to sophisticated structures at difficult sites.

IID691 (2491) Design Project in Geotechnical Engineering (u,g). On demand. Credit one to six hours. Staff.

Design problems frequently associated with the Master of Engineering program.

IID693 (2493) Seminar in Geotechnical Engineering (u,g). On demand. Credit one to two hours. Staff.

Presentation and discussion of technical papers and current research in the general field of geotechnical engineering or one of its specialized fields.

IID694 (2494) Special Topics in Geotechnical Engineering (u,g). On demand. Credit one to six hours. Staff.

Supervised study in small groups in one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

IID712 (2412) Graduate Soil Mechanics Laboratory (g). Spring. Credit three hours. Prerequisite: IID610. D. A. Sangrey.

Laboratory measurement of soil properties: classification tests; direct shear tests; triaxial tests for the measurement of pore water pressure; strength parameters. Pore pressure dissipation tests. Relationship of laboratory tests to field behavior.

IID714 (2414) Advanced Geotechnical Engineering (g). Fall. Credit three hours. Three lectures. Prerequisite: IID606 or equivalent. J. N. Kay.

A review in more intensive detail of topics covered in IID606, with additional discussion of recent improvements. Topics include site investigations; theories of bearing capacity for shallow and deep foundations; earth pressure on retaining walls, braced excavations, sheet pile walls, and tunnels; settlement and consolidation.

IID715 (2415) Soil Dynamics (g). Fall. Credit three hours. Three lectures. Prerequisite: consent of instructor. D. A. Sangrey.

Introduction to principles of the vibration of simple systems under harmonic and transient loading. Energy propagation by waves through solid and layered systems. Detailed consideration of the response of soils to dynamic and repeated loading, and the measurement of these characteristics. Analytical models of simple foundations on elastic media and analogues useful for design. Analysis and design examples.

IID718 (2418) Case Studies in Soil Mechanics and Foundation Engineering (g). Spring. Credit three hours. Prerequisite: IID610. Staff.

Study of real engineering problems of various types; importance of the geological environment in recognizing the nature of field problems; application of mechanics and soil properties to obtain engineering solutions. Preparation of engineering reports.

IID792 (2492) Research in Geotechnical Engineering (g). On demand. Credit one to six hours. Staff.

For students who wish to study one particular area of geotechnical engineering in depth. The work may take the form of a laboratory investigation, field study, theoretical analysis, or the development of design procedures.

Environmental Protection and Management

IIE301 (2501) Environmental Quality Engineering (u). Spring. Credit three hours. Three lecture-recitations. Prerequisite: upperclass standing in College of Engineering or permission of instructors. A. Wm. Lawrence and D. P. Loucks.

Concepts of environmental quality, including ecological, resource, socioeconomic, and political-administrative considerations. Objectives and methods of environmental quality control, with emphasis on air, water, land, noise, and radioactivity. Introduction to natural phenomena, technology, and analytical skills pertinent to environmental quality control.

IIE602 (2502) Water Quality Engineering (u,g). Fall. Credit three or four hours. Three lectures, one laboratory or computing session. Prerequisite: IIC301 or IIE301, or equivalent, or permission of instructor. J. J. Bisogni.

Introduction to water quality engineering, including water supply, and water and wastewater treatment and disposal. Principles applicable to the behavior of municipal and industrial effluents in natural waters. Elements of analysis and design of municipal water supply systems and wastewater and storm water collection and disposal systems.

IIE610 (2510) Chemistry of Water and Wastewater (u,g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: one year of college chemistry and permission of instructor. J. J. Bisogni.

Principles of physical, organic, inorganic, and biochemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters.

IIE611 (2511) Aquatic Chemistry (g). Spring. Credit three hours. Three lectures. Prerequisite: IIE610 and Chemistry BCH287–288. J. J. Bisogni.

Chemical equilibrium in natural aquatic systems, including water and wastewater treatment systems. Chemical thermodynamics, acid-base systems, oxidation-reduction systems, coordination chemistry, solid-liquid-gas interfaces with regard to precipitation, dissolution, and adsorption. Emphasis on phenomena, mathematical solution of chemical equilibrium, and application to engineering management of water quality.

IIE613 (2513) Biological Phenomena and Processes (u,g). Fall. Credit four hours. Three lectures, one laboratory. Prerequisite: IIE602 or equivalent and concurrrent registration in IIE610. A. Wm. Lawrence.

Theoretical and engineeirng aspects of biological phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes, and to their stabilization in receiving waters. Pertinent microbiological principles, biological oxidation kinetics, and eutrophication. Analysis and design of biological treatment processes. Laboratory studies of pertinent phenomena and processes.

IIE614 (2514) Chemical and Physical Phenomena and Processes (u,g). Spring. Credit four hours. Three lectures, one laboratory. Prerequisite: IIE610 and IIE613. A. Wm. Lawrence.

Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, wastewater, industrial wastes, and receiving waters; reaction kinetics, transfer and dispersion phenomena, and fine particle mechanics. Analysis and design of conventional and advanced treatment and disposal processes. Laboratory studies of pertinent phenomena and processes.

IIE615 (2515) Water Resources Problems and Policies (u,g). Fall. Credit three hours. Lecture-discussion. Prerequisite: permission of the instructor. Intended primarily for graduate engineering and nonengineering students but open to qualified undergraduates. L. B. Dworsky.

A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water problems, organization, and policies.

IIE620 (2520) Environmental Quality Control (u,g). Spring. Credit three hours. Three lecture-discussions. Prerequisite: permission of instructor. Intended primarily for graduate students and seniors in engineering. C. D. Gates.

An introduction to environmental pollution problems, their nature and dimensions, and their impact on man. Principles and methods underlying environmental quality control; engineering, environmental health, regulatory, and technological aspects of control. Emphasis on air and water quality standards and legislation, solid wastes.

[IIE630 (2530) Solid Waste Management (u,g). (Same as Agricultural Engineering OAE675.) Spring. Credit three hours. Three lectures, reports. Prerequisite: permission of instructor. R. C. Loehr. Not offered in 1973–74.

Study of municipal, industrial, and agricultural solid wastes. Emphasis on waste characteristics, methods of treatment and disposal, and interrelationships with air, water, and land environment. Discussion of economic and political aspects. Intended primarily for graduate students, but open to qualified undergraduates.]

IIE631 (2531) Industrial Waste Engineering (u,g). (Same as Agricultural Engineering OAE676 and Chemical Engineering IHE622.) Spring. Credit three hours. Primarily a graduate course, but open to upperclassmen in Civil and Environmental, Agricultural, or Chemical Engineering, or in the College Program with a major from these fields.

Offered jointly with Agricultural Engineering and Chemical Engineering as an integrated presentation. In the first third, concern is with legal aspects, assimilatory capacity of receiving waters, joint industrial-municipal collection of wastes, and sewerage service charges. The second part covers waste sampling and analysis, treatment processes, waste-reduction possibilities, water quality and quantity, water reuse and recovery, and costs. The third part treats specific industrial operations and selected case studies of industrial waste treatment. A study, in depth, of a particular waste problem is required of all students.

IIE633 (2533) Environmental Quality (u,g). Fall; spring on demand. Credit three hours. Three lecture-discussions. Field trips. Prerequisite: upperclass or graduate student status. C. D. Gates.

An introduction to environmental quality and pollution problems, their nature, causes, and control. Man's interaction with the air-land-water resource. Engineering and regulatory aspects of environmental quality management, with emphasis on control of air quality, water quality, and solid wastes.

IIE634 (2534) Air Quality Control (u,g). Spring. Credit three hours. Three lecture-discussions. Prerequisite: upperclass or graduate student status. C. D. Gates.

An introduction to air quality and air pollution problems. Sources, natures, and effects of specific air pollutants, their dispersion, and interactions in the atmosphere. Air quality standards, regulations, and legislation. Air quality control methods and technology.

IIE645 (2545) Water Resources Planning Seminar (u,g). Spring. Credit three hours. Prerequisite: IIE615 or permission of instructor. L. B. Dworsky.

The concepts, processes, and techniques of regional, multipurpose river basin planning and development. The case study method, including the preparation of an integrated, comprehensive report for the study area.

IIE693 (2593) Environmental Protection and Management Colloquium or Seminar (u,g). Fall and spring. Credit one to two hours. Required of graduate students majoring or minoring in sanitary engineering. Open to undergraduates with permission of the instructor.

Presentation and discussion of current topics and problems in sanitary engineering and water resources engineering.

IIE718 (2518) Water Resource Systems (g). Spring. Credit three hours. Prerequisite: IIB201, IIF617, or IOE622, or permission of instructor. D. P. Loucks.

Application of economics, engineering, and systems theory to water, wastewater, and related resource planning and management problems. Development of deterministic and stochastic models. Review of current literature.

IIE791 (2591) Design Project in Water Resource Engineering or in Sanitary Engineering (g). On demand. Credit variable. Prerequisite: IIE301 or IIE602 or equivalent. Staff.

The student will elect or be assigned problems in the design of water and wastewater treatment processes or plants; wastewater disposal systems; water quality control systems; water resource development or management systems; or laboratory apparatus of special interest.

IIE792 (2592) Sanitary Engineering Research (g). On demand. Credit variable. Prerequisites will depend on the particular investigation to be undertaken. Staff.

For the student who wishes to study a special topic or problem in greater depth than is possible in formal courses.

IIE794 (2594) Special Topics in Sanitary and Water Resource Engineering (g). On demand. Hours and credit variable. Staff.

Supervised study in special topics not covered in formal courses.

Public Systems and Transportation

IIF303 (2603) Engineering Economics and Systems Analysis (u). Spring. Credit three hours.

Aimed at the junior-senior level. Intended to give the student a working familiarity with the principles and main analytical techniques for reaching decisions about the economic aspects of engineering projects. Concepts of economic decisions; choice among alternatives; break-even and minimum-cost analysis; inventory control; resource allocation and scheduling; concepts of interest, depreciation, and replacement of assets. Decisions under conditions of risk and uncertainty. Introduction to systems analysis as a quantitative basis for public policy decisions; optimization, linear programming, critical path scheduling, elementary queuing and game theory. Not intended for students with substantial background in business economics or methods of operations research.

IIF605 (2605) The Law and Environmental Control (u,g). Fall. Credit four hours. Prerequisite: permission of instructor. Designed for seniors and graduate students. P. L. Bereano.

An introduction to the structure and operation of the legal system and an investigation of the manner in which that system may handle environmental problems. The interaction of law and science; regional problems and political jurisdictional boundaries (the interstate compact); the police power of the states; statutory law and case law; the judicial function; the nature and functions of the administrative agencies; environmental regulation; recent environmental case law.

IIF606 (2606) Seminar in Technology Assessment (u,g). Spring. Credit three hours. Prerequisite: permission of instructor, based on a showing of adequate background. P. L. Bereano and others.

An interdisciplinary seminar dealing with the social consequences of future technological development and means by which technology can be guided in socially beneficial directions. Topics include: governmental institutions, such as the Congress, courts, and regulatory agencies, and the manner in which they handle technical problems; economic considerations and the role of the market; the planning process (prediction, role of normative considerations, creation and evaluation of alternative courses of action, and feedback considerations); existing assessment mechanisms and institutions in the private and public sectors, and proposed new structures; opportunities for public participation. Student-faculty task forces will organize to undertake projects exploring aspects of technology assessment theory and methodology, do case studies, perform simple assessments, or investigate questions pertaining to the design and functioning of institutions to perform such tasks.

IIF611 (2611) Economic Analysis of the Private Sector (Microeconomics) (u,g). Fall. Credit four hours. Prerequisite: one year of college-level mathematics. R. E. Schuler.

Considers the economic behavior of individual households and firms; how individual agents combine under different market structures, including competitive markets, monopoly, and monopsony; and the theory of distribution and general equilibrium. Most topics will receive both graphical and mathematical treatment.

IIF612 (2612) Economic Analysis of Government (u,g). Spring. Credit four hours. Prerequisite: one year of college-level mathematics and IIF611; or Economics 311. R. E. Schuler.

A continuation of IIF611. First half: consideration of the welfare implications of various forms of economic organization and the rationale for government intervention in the microeconomy. The theory underlying investment in government projects and environmental programs will be studied. Second half: national economic constraints and aggregate behavior (macroeconomics), and the impact of government activity of these aggregates. Mathematical as well as graphical tools of analysis will be used.

[IIF613 (2613) Macroeconomic Theory (u,g). Credit four hours. Prerequisite: IIF612. May not be offered in 1973–74.

National income accounting. Money and banking. Federal Reserve policy. Classical model of employment. Inflation. Keynesian model of income determination. Theories of consumption and investment. Fiscal policy. Foreign trade. Dynamic macro models. Accelerator-multiplier interaction. Harod-Domar growth model. Neoclassical growth models. Population growth. Regional development models.]

IIF617 (2617) Public Systems Analysis I (u,g). Fall. Credit one to three hours. Prerequisite: IOC320 or IOE622, which may be taken concurrently.

An introduction to the use of systems analysis in structuring public decision problems.

IIF618 (2618) Public Systems Analysis II (u,g). Spring. Credit three hours. Prerequisite: IIF611, IIF617, IOC320 or IOE622, IOA260 or IOD660, and IOC361 or IOE623, which may be taken concurrently.

The use of mathematical modeling, simulation, optimization, and other systems analysis techniques to aid in management decisions in a broad class of environmental and public systems problems. A survey of applications in areas of transportion, water resources, governmental services, and public health systems.

IIF619 (2619) Environmental Systems Analysis (u,g). Fall. Credit three hours. Prerequisite: IIF618. D. P. Loucks.

Application of systems analysis and economics to water resource and environmental quality management. Design and operation of water resources systems. Evaluation of public policy alternatives for air, land, and water resources and the material and energy wastes released into the environment. Development of deterministic and stochastic models for steady-state and dynamic conditions.

IIF620 (2620) Transportation Engineering (u,g). Fall. Credit three hours. G. P. Fisher.

Transportation systems analysis; traffic generation, distribution, and assignment models; modal split models. Elements of traffic flow theory and congestion analysis. Terminals and transfer delays. Physical environment evaluation, including route location and use of aerial photography. Transport economics and current policy issues. Technological and economic characteristics of current transportation modes.

IIF621 (2621) Urban Transportation Planning I (u,g). Fall. Credit four hours. Prerequisite for most other courses in transportation area Prerequisite: a basic microeconomics course. Designed primarily as a first course in transportation planning, leading to one or more of the other transportation courses. It may, however, be taken as an introductory, or overview course, in transportation planning. M. H. Meyburg.

The urban transportation problem, its roots, manifestations and implications; the systems analysis approach to transportation; the demand and supply side of transportation; the urban transportation planning process; generation of alternatives and their evaluation; and introduction to decision theory.

[IIF622 (2622) Multivariate Analysis Methods in Transportation (u,g). Fall (alternate years only). Credit four hours. Prerequisite: IOA260, IOA270, or equivalent; and IIF621, which may be taken concurrently. Intended primarily for graduate students, but qualified seniors may be admitted with permission of instructor. Not offered in 1973–74.

Multivariate methods for statistical model building in transportation and other urban systems. Linear and nonlinear regression analysis, weighted regression, canonical correlation, factor analysis, simultaneous equations methods, discriminant analysis, probit analysis, and logit analysis. Applications to transportation demand modelling.]

[IIF623 (2623) Urban Transportation Planning II (u,g). Spring (alternate years only). Credit three hours. Prerequisite: IIF611, IIF612, IIF621, IIF622, or permission of instructor. Intended primarily for graduate students, but qualified seniors may be admitted with permission of instructor. Not offered in 1973–74.

Advanced instruction in conventional models of travel demand in transportation studies, including residential and nonresidential trip generation; Fratar, Gravity and opportunity models of trip distribution; trip-end and trip-interchange modal split; network assignment. New methods of travel demand modelling, including spatial distribution theories, "abstract mode" models, and individual behavior theories. The propagation of errors in models.]

IIF624 (2624) Transportation Systems Analysis (u,g). Spring. Credit three hours. Prerequisite: IOA260, IIF621, IOC622, IOC320, or permission of instructor. A. H. Meyburg.

Techniques of systems analysis as applied to the physical planning, operation, and financing of transportation facilities. Wherever applicable, mathematical models of transportation processes are used to examine questions related to the development of optimal public policy decisions in the area of transportation. Attention is given to analysis of single and multi-modal forms of transportation. Methods of mathematical programming, simulation, and stochastic processes are employed.

[IIF640 (2640) Traffic Flow Theory (u,g). (Same as Industrial Engineering and Operations Research IOE627.) Spring. Credit three hours. Prerequisite: IIF621. Not offered in 1973–74.

Study of various mathematical theories of traffic flow. Microscopic models (car following models). Macroscopic models (kinematic wave theory). Stochastic properties of traffic flow at low density. Probability models for traffic lights and optimal control of signalized intersections. Traffic flow on transportation networks. Application to traffic assignment. Traffic network simulation system.]

[IIF641 (2641) Airport Planning and Operations (u,g). Spring (alternate years only). Prerequisite: IIF621 or permission of instructor. A. H. Meyburg. Not offered in 1973–74.

The role of air travel within overall transportation system; terminal access; location and site selection; terminal design and operations; metropolitan air transit systems; environmental impact of airport location; air traffic flow analysis; air traffic control; aircraft technology.]

IIF643 (2643) Design and Planning of Mass Transportation (u,g). Spring (alternate years only). Credit three hours. Prerequisite: IIF621 or permission of instructor.

A study of mass transportation of the past and present; innovative forms of mass and individual transportation in urban areas. The financing and organization of mass transportation; the "free transit"-fares dilemma. Planning for mass transportation: special applications; implementation of plans; planning transportation in new towns.

IIF644 (2644) Transportation Systems Evaluation (u,g). Spring. Credit three hours. Prerequisite: IIF621 and a basic microeconomics course.

Economic evaluation techniques; measures of effectiveness; cost-effectiveness evaluation; definition of goals, objectives, and criteria for transportation planning; impact analysis and evaluation.

IIF747 (2647) Environmental Policy Analysis (g). Fall. Credit three hours. Prerequisite: IOA260, IIE618 or IIE718, IIF611 or equivalent, or permission of instructor. D. P. Loucks.

Current research topics concerning the application of economic and simulation techniques to the definition and evaluation of public policy alternatives for managing air, land, and water resources and the material and energy wastes released into the environment. The influence of technologic, economic, and political uncertainty will be emphasized. Each student will be expected to select a particular environmental management problem and structure models or methods for analyzing alternative solutions.

IIF751 (2651) Environmental Quality Management for Agro-Ecosystems (g). (Same as Agricultural Engineering OAN510.) Fall. Credit three hours. Prerequisite: some knowledge of linear programming or permission of the instructors. C. Shoemaker and D. A. Haith.

The application of systems analysis and mathematical ecology to problems in ecosystem management and environmental quality. Topics selected from the following: pest control, fertilizer usage, eutrophication, agricultural waste, soil and water conservation, and public policy decisions affecting ecosystem management.

IIF780 (2680) Environmental Control Workshop (g). Spring. Credit one to three hours by arrangement with instructor. W. R. Lynn.

Students interested in research topics dealing with control of the environment (with special emphasis on biological and ecological aspects) are encouraged to participate in this workshop. Topics discussed in previous workshops include human population control, control of pest and parasite populations, study of species' strategic use of food supply, control of populations by use of predators, and host-parasite systems. Additional topics will be developed.

IIF791 (2691) Public Systems Analysis Design Project (g). On demand. Credit variable. Prereqiusite: permission of instructor. May extend over two semesters. Staff.

Design of feasibility study of public systems, supervised and assisted by one or more faculty advisers. Individual or group participation. Final report required.

IIF792 (2692) Public Systems Analysis Research (g). On demand. Credit variable. Prerequisite: permission of instructor. Preparation must be suitable to the investigation to be undertaken. Staff.

Investigation in depth of particular public systems problems.

IIF793 (2693) Public Systems Planning and Analysis Colloquium (u,g). Either term. Credit one hour.

Lectures in various topics related to public systems planning and analysis.

IIF794, IIF795 (2694, 2695) Special Topics in Public Systems Planning and Analysis (g). On demand. Credit variable. Staff.

Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

Structural Engineering

IIG301 (2701) Structural Engineering I (u). Fall. Credit four hours. Three lectures, one two-hour period. Prerequisite: Mechanics IAK221. Evening preliminary examinations. Staff.

Introduces the fundamental concepts of structural engineering analysis and behavior. First course in a four-course sequence of structural theory, behavior, and design. Structural planning, loads, structural form, analysis of statically determinate systems, approximate analysis of statically indeterminate systems, introduction to the behavior of simple steel and concrete members.

IIG302 (2702) Structural Engineering II (u). Spring. Credit four hours. Three lectures, one two-hour period. Prerequisite: IIG301. Evening preliminary examinations. Staff.

Presents the fundamentals of the calculation of displacements and the analysis of statically indeterminate structures, and uses these as basis for further understanding of structural behavior and design. Virtual work; flexibility and stiffness methods including moment distribution; plastic behavior; analysis for moving loads. Applications to steel and concrete structures.

IIG303 (2703) Structural Engineering III (u). Fall. Credit three hours. Prerequisite: IIG302 and IIG351 (may be taken concurrently), or consent of instructor. Staff.

Continues the study of the behavior of structures. Behavior and design of steel, concrete, and timber structural elements, connections, and systems.

IIG304 (2704) Structural Engineering IV (u). Spring. Credit three hours. Prerequisite: IIG303. Staff.

The objective is to develop an understanding of the structural design process. Comprehensive design project, drawing on material from previous courses in structures and materials. Additional topics such as preliminary design, choice of form, shells, models.

IIG305 (2705) Structural Behavior Laboratory (u). Spring. Credit two hours. May be taken concurrently with IIG302 or IIG304. R. N. White.

A laboratory course on behavior of structures, utilizing small-scale models. Elastic, inelastic, and nonlinear behavior of structural components and systems, including beams, beam-columns, trusses, frames, grids, plates, and shells in both metal and reinforced concrete. Individual projects.

IIG351 (2751) Engineering Materials (u). Fall. Credit three hours. Two lectures, one laboratory. F. O. Slate.

Engineering properties of concrete, steel, wood, and other selected structural materials; physicochemical properties of soils, concrete, and bituminous materials. Design characteristics and significance of test results of materials used in engineering works. Extensive laboratory testing and report writing.

IIG610 (2710) Strength of Structures (u,g). Fall. Credit three hours. Prerequisite: IIG303 (can be taken concurrently). G. Winter.

Concepts of structural safety. Analysis of stress, strain, and strength in bi- and triaxial loading. Theories of failure of ductile and brittle materials. Performance of structural materials and members under load: strain hardening, Bauschinger effect, residual stresses, effects of stress concentrations, creep. Design for brittle fracture and fatigue. Inelastic bending of beams. Limit design of steel and reinforced concrete structures. Critical discussion of recent research and current design codes.

IIG611 (2711) Buckling: Elastic and Inelastic (u,g). Spring. Credit three hours. T. Peköz.

Analysis of elastic and plastic stability. Determination of buckling loads and post-buckling behavior of columns. Solid and open web columns with variable cross-section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral strength of unbraced beams. Buckling loads and postbuckling behavior of plates, shear webs, and cylindrical shells. Critical discussion of current design specification.

IIG612 (2712) Advanced Structural Analysis (u,g). Fall. Credit three hours. Three lectures. Prerequisite: IIG302. A. H. Nilson.

Stability, determinacy, redundancy of structures. Approximate methods of analysis. Force, displacement, and transfer matrix methods of matrix structural analysis. Development of space frame element equations, including distributed loads and thermal strain effects. Methods of solution: direct and iterative, tridiagonalization, partitioning, and special transformations. Analysis techniques for tall buildings and other special problems.

[IIG613 (2713) Finite-Element Analysis (u,g). Spring. Credit three hours. Three lectures. Prerequisite: IIG612. R. H. Gallagher. Not offered in 1973–74.

Theoretical and conceptual bases for formulation of finite-element representations in structural analysis. Development of element relationships for structural analysis of plates, shells, and solids. Extension of element- and system-solution techniques to deal with problems in elastic stability, inelastic deformation, finite displacements, dynamic response, and other special behavior mechanisms.]

IIG614 (2714) Structural Model Analysis and Experimental Methods (u,g). Spring. Credit three hours. Two lectures, one two-hour period. Prerequisite: indeterminate analysis. R. N. White.

Dimensional analysis and principles of similitude. Direct model analysis, including materials, fabrication, loading, and instrumentation techniques. Basic techniques of experimental stress analysis. Confidence levels for model results. Laboratory projects in elastic behavior and ultimate strength of model structures.

[**IIG615 (2715) Probabilistic Concepts in Structural Engineering (u,g).** Spring. Credit three hours. Prerequisite: IIG303. R. G. Sexsmith. Not offered in 1973–74.

Introduction to probability concepts pertaining to engineering design and reliability; probabilistic models; inference techniques; decision analysis; stochastic processes; applications in structural safety decisions and structural random vibration.]

IIG616 (2716) Prestressed Concrete Structures (u,g). Fall. Credit three hours. Three lectures. Prerequisite: IIG303; IIG304 recommended. A. H. Nilson.

Behavior, analysis, and design of prestressed concrete structures; pretensioning, post-tensioning, precast construction; beams, slabs, composite members, continuous beams and frames, tension and compression members; prestress losses, section efficiency, end zone stresses, deflection analysis, cracking, partial prestressing.

IIG617 (2717) Advanced Reinforced Concrete (u,g). Spring. Credit three hours. Three lectures. Prerequisite: IIG303; IIG304 recommended. A. H. Nilson.

Behavior, analysis, and design of reinforced concrete structures; strength, safety considerations, deflection analysis, crack control, limit analysis, yield line theory; flexure, shear, torsion, axial loads, slenderness effects; beams, columns, slabs, continuous frames, two-way systems, composite construction, deep beams, ground-supported slabs, shear walls, folded plates.

IIG618 (2718) Behavior and Design of Metal Structures (u,g). Fall. Credit three hours. Prerequisite: IIG303; IIG304 recommended. W. McGuire.

Contemporary methods for analyzing and designing metal structures. Behavior of structural elements and frames. Selected design applications from the fields of steel plate structures, bridges, suspension systems, lightweight structures.

IIG620 (2720) Shell Theory and Design (u,g). Fall. Credit three hours. Prerequisite: IIG302 and consent of instructor. P. Gergely.

The fundamentals of practical shell theory. Differential geometry of surfaces; membrane and bending theory of shells; analysis and design of cylindrical shells, polygonal domes, and paraboloids. Application to reinforced concrete roofs and pressure vessels. Introduction to the stability of shells.

IIG622 (2722) Structural Design for Dynamic Loads (u,g). Spring. Credit three hours. Prerequisite: IIG303, some computer programming experience, and consent of instructor. P. Gergely.

A broad study of the analysis, design, and behavior of structures subjected to dynamic effects, with emphasis on earthquake-resistant design. Vibration of simple systems; response spectra; numerical, energy, and matrix methods of analysis. Basic seismology. Analysis and design of structures for earthquakes, including inelastic effects. Modern design approaches.

[**IIG630–631 (2730–2731) Transportation Structures (u,g).** Fall and spring. Credit three hours. Offered in alternate years. Prerequisite: IAK221. R. H. Gallagher. Not offered in 1973–74.

Treatment of structural design aspects of land, sea, and air vehicles. Description of applicable design specifications, design environments, materials failure criteria, forms of construction, and methods of structural analysis. Each student will be required to submit a term paper.]

IIG652 (2752) Advanced Plain Concrete (u,g). Spring. Credit three hours. Two lectures plus conference. Prerequisite: IIG351 or equivalent. F. O. Slate.

Topics in the field of concrete, such as history of cementing materials, air-entrainment, light weight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relatonships among internal structure, physical properties, chemical properties, and the mechanical properties of interest to the design and construction engineer.

IIG653 (2753) Structure and Properties of Materials (u,g). Spring. Credit three hours. Offered spring 1974 and alternate springs thereafter. Two lectures plus conference. Open to graduate students in engineering or the physical sciences or to undergraduates by consent of the instructor. F. O. Slate.

Internal structure of materials ranging from the amorphous to the crystalline state. Forces holding matter together versus forces causing deformation and failure. Correlation of the internal structures of materials with their physical and mechanical properties. Applications to various engineering materials.

[IIG654 (2754) Low-Cost Housing Primarily for Developing Nations (u,g). Offered alternate spring terms; not offered in 1974. Credit three hours. Two lectures plus conference. F. O. Slate.

A multidisciplinary course involving faculty members from the College of Architecture, Art, and Planning, and the College of Human Ecology. Students will do intensive study, usually in their own discipline, for a term project, while also being introduced to problems and approaches of other disciplines. For engineers, the primary purpose is to investigate the technological aspects of the subject, and other aspects that influence technological decisions, such as cultural and economic factors. Typical technological aspects are indigenous materials, structural systems, construction, maintenance, and effects of the physical environment. Coverage is from agrarian-rural to industrial-urban.]

IIG690 (2790) Planning of Structural Systems (u,g). Fall. Credit three hours. Prerequisite: IIG302. T. Peköz.

Functional, structural, and other considerations in the planning and selection of structural systems. Probabilistic description of loading and strength. Preliminary design—estimating overall dimensions and weights, proportioning of members and joints—and optimization. Preliminary analysis of frames, trusses, plates, and shells. Erection, construction, and stress control considerations. Computer structural analysis. Case studies with the participation of practicing engineers.

IIG693 (2793) Structural Engineering Seminar (u,g). Fall and spring. Credit one to three hours. Open to qualified seniors and graduate students. Staff.

Preparation and presentation of topics of current interest in the field of structures for informal discussion.

IIG694 (2794) Special Topics in Structural Engineering (g). On demand. Hours and credit variable. Staff.

Individually supervised study in one or more of the specialized topics of civil engineering, such as tanks and bins, suspension bridges, towers or movable bridges, which are not covered in the regular courses. Independent design or research projects may also be selected.

[IIG732 (2732) Optimum Structural Design (g). Fall. Credit three hours. R. H. Gallagher. Not offered in 1973–74.

Treats the procedures to be applied in order to design minimum weight or minimum cost structures. Coverage encompasses simplified ideas such as fully-stressed design, classical minimization procedures, and modern methods based on mathematical programming schemes.]

IIG757 (2757) Civil and Environmental Engineering Materials Project (g). On demand. Credit one to six hours. F. O. Slate.

Individual projects or reading and study assignments involving engineering materials.

IIG791 (2791) Design Project in Structural Engineering (g). (Meets project requirement for M. Eng. degree for students who cannot enroll in IIK510–511.) Fall and spring. Credit variable. Coregistration in IIG690 during fall term required. Staff.

Comprehensive design project by teams. Formulation of alternate proposals, including economics and planning, for a given situation and complete design of the best alternative. Determination of construction costs and preparation of sketches and drawings. Presentation of designs by oral and written reports.

IIG792 (2792) Research in Structural Engineering (g). On demand. Hours and credit variable. Staff.

For students wishing to pursue one particular branch of structural engineering further than can be done in any of the regular courses. Prerequisite courses depend upon the nature of the work desired. The work may be an investigation of existing types of construction, theoretical work with a view of simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

Professional Practice

IIK502 (2002) Civil and Environmental Engineering Practice (u,g). On demand. Credit three hours. Prerequisite: fourth year or graduate standing. Staff.

Analysis of large engineering works; planning and organizing engineering and construction projects; professional practice; feasibility evaluations; financial justification of projects; social and political implications. The case method is used extensively.

IIK510 (2010) Civil and Environmental Engineering Design Project I (g). Fall. Credit one or two hours. Normally required for students in the M.Eng. (Civil) program. Staff.

First term of a two-term sequence. Design of a major civil engineering project embodying several aspects of civil engineering. Planning and part of preliminary design to be accomplished in the fall term; remainder of preliminary design and final design in the spring term. Projects to be carried out by students working under the direction of a faculty project coordinator.

IIK511 (2011). Civil and Environmental Engineering Design Project II (g). Spring. Credit three hours. Prerequisite: IIK510. Normally required for students in the M.Eng. (Civil) program. Continuation of IIK510. Staff.

IIK520–521 (2020–2021) Professional Practice in Engineering (g). Fall: IIK520. Spring: IIK521. Credit three hours a term. Required of each candidate for the M.Eng. (Civil) degree. Enrollment limited to candidates for the professional Master of Engineering degrees.

The objective is to introduce the student to the business, professional, and managerial aspects of the professional practice of engineering. Emphasis is placed upon legal, financial, social, and ethical aspects. Other topics include: personnel management, labor relations, professional registration and organizations, and engineering communications.

IIK801 (2001) Thesis (g). The thesis gives the student an opportunity to work out a special problem or make an engineering investigation, to record the results of his work, and to obtain academic credit for such work. Registration for the thesis must be approved by the professor in charge at the beginning of the semester during which the work is to be done. Individual courses may be arranged to suit the requirement of graduate students. They are intended to be pursued under the immediate direction of the professor in charge, the student usually being free from the restriction of the classroom and working either independently or in conjunction with others taking the same course.

Computer Science

ICS100 (100) Introduction to PL/I programming (u). Either term. Equivalent to two hours credit. Students *do not register directly in ICS100,* but rather register in a course that includes participation in ICS100 as a portion of course requirements (see ICS101, ICS102, and IBE105). Lectures, T Th 9:05 or T Th 11:15, first eight weeks of term only. No scheduled recitation or laboratory, but optional recitation offered every afternoon Monday through Friday 2:30–4:25.

An elementary presentation of computer programming, using the PL/I language. Presents material common to several introductory courses. No previous programming experience is assumed. Problem analysis, program design, programming style, and conventions are emphasized. The presentation is essentially nonmathematical, and can serve as a basis for programming of either numeric or nonnumeric applications. Problems are assigned to be programmed in PL/I and processed on the computer.

ICS101 (201) Survey of Computer Science (u). Either term. Credit three hours. T Th 9:05.

Introduction to the structure and use of the modern computer. An overview of the material with emphasis on nonnumeric computer applications, such as information retrieval, language processing, and artificial intelligence. ICS100 is used to teach programming in the language PL/I. Programming and debugging problems on the computer.

ICS102 (311) Introduction to Computer Programming (u). Either term. Credit one, two, or three hours. T Th 11:15.

Applications of the PL/I and FORTRAN IV programming languages to solve simple numerical and nonnumerical problems using a digital computer. ICS100 is used to teach programming in the PL/I language; this part only may be taken for two hours credit. The FORTRAN part only may be taken for one hour credit; ICS100 is assumed as a prerequisite. Both parts may be taken for three hours credit.

ICS105 (305) The Computerized Society (u). Fall. Credit three hours. T Th 1:25.

A seminar-style course designed to bring the perspectives of the sciences, social sciences, and humanities to the question of the impact of computers on society. Enrollment will be limited to thirty students of varied backgrounds who show an interest in the present-day influences of computers on human life and the future alternatives in the application of computers to society. Topics include: the potentialities and limitations of the computer—the popular view *versus* the computer scientist's view; man and the machine—the identity crisis; human privacy and the national data banks; human decision making *versus* military and industrial automation; the knowledge explosion and information-retrieval systems; technological and occupational obsolescence—what price for progress?; social structure in the year 2000.

ICS211 (202) Computers and Programming (u). Either term. Credit three hours. Prerequisite: ICS100 or equivalent programming experience. Lectures, M W 9:05 or T Th 10:10. Laboratory, M T W Th or F 2:30–4:25.

Intended as a foundations course in computer programming. Algorithms and their relation to computers and programs. Analysis of algorithms in terms of space and time requirements. A procedure-oriented language: specification of syntax and semantics, data types and structures, statement types, input-output, program structure. A brief introduction to machine organization. Programming and debugging problems on a computer.

ICS280 (203) Discrete Structures (u). Fall. Credit three hours. Prerequisite: ICS101 or ICS211. M W F 1:25.

Fundamental mathematical concepts relevant to computer science. Set algebra, mappings, relations, partial ordering, equivalence relations, congruences. Operations on a set, groups, semigroups, rings and lattices, isomorphism and homomorphism, applications to automata and formal languages. Boolean algebra, applications to switching theory and decision tables. Directed and undirected graphs, subgraphs, chains, circuits, paths, cycles, graph isomorphism, application to syntactic analysis and computer program analysis.

ICS314 (401) Introduction to Computer Systems and Organization (u,g). Either term. Credit four hours. Prerequisite: ICS211 or equivalent programming experience. T Th 11:15. Laboratory, M T W Th or F 2:30–4:25.

Characteristics and structure of digital computers as hardware units. Representation of data, addressing of data, index registers, indirect and base-plus-displacement addressing. Introduction to computer microstructure, gates, flip-flops, and adders. Storage and peripheral hardware and their characteristics, the input-output channel, and interrupts. Assembly language programming: format and basic instructions, the assembly process, loops and indexing, data types, subroutines, macros. Brief description of operating systems, loaders, interpreters, and compilers. Programming and debugging assembly language programs on a computer.

ICS321–322 (321–322) Introduction to Numerical Analysis (u). Throughout the year. Credit four hours a term. Prerequisite: Mathematics BMA222 or BMA294 and knowledge of a programming language such as FORTRAN, ALGOL, or PL/I. M W F 1:25.

Emphasis on algorithms appropriate for use with computers. Students solve representative problems on the computer by programming these algorithms. Numerical methods for solving systems of linear equations and calculating eigenvalues and eigenvectors. Interpolation, differentiation, least squares and Chebyshev solution to discrete and continuous systems, and integration. Numerical solution of ordinary and partial differential equations. Solution of nonlinear equations in several variables.

ICS410 (409) Data Structures (g). Fall. Credit four hours. Prerequisite: ICS314 or equivalent. T Th 9:05, W 2:30.

Data structures, relations between data elements, and operations upon data structures. Lists, trees, graphs, and other forms of data structures. List operations including linear lists, circular lists, arrays, orthogonal lists, and multilinked structures. Binary tree representation, tree traversal, infinity lemma, tree enumeration. Lists and garbage collection. Dynamic storage allocation. Search and sorting techniques.

ICS414 (404) Advanced Computer Programming (g). Spring. Credit four hours. Prerequisite: ICS314 or consent of instructor. T Th 1:25, F 2:30.

Intended for students who wish to learn computer programming for eventual use in professional systems programming or advanced applications. Basic logical and physical structure of digital computers is considered; the applicability and limitations of this structure are studied through many examples and exercises. The approach, therefore, is not a theoretical one, but rather an engineering one, in which techniques are emphasized. Students are expected to participate in a large systems programming design and implementation effort.

ICS435 (435) Information Organization and Retrieval (g). Spring. Credit four hours. Prerequisite: ICS314 or equivalent. T Th 9:05; occasionally W 2:30.

Introduction to information retrieval. File organization and search algorithms. Statistical analysis and automatic classification of information. Structural language analysis. Dictionary techniques. Interactive retrieval. Question and answering and data base retrieval. Evaluation of retrieval effectiveness.

ICS481–482 (485–486) Introduction to Theory of Computing I, II (u). Throughout the year. Credit four hours a term. Prerequisite: ICS211, ICS280, or equivalent mathematics, or consent of instructor. M W F 11:15.

Introduction to modern theory of computing: major results from automata theory, formal languages, effective computability, computational complexity, and analysis of algorithms. Definition of abstract computing models including finite automata, push-down automata, Turing machines, and random access machines; their relation to formal languages and effective computability (regular sets, context-free languages, parsing algorithms, recursively enumerable sets, etc.); and unsolvable problems related to these models, including the halting problem, equivalence and ambiguity problems for languages, Rice's theorem, etc. Quantitative problems in computing considered in terms of computational complexity theory, which includes computational complexity measures, properties of complexity classes, and gap and speed-up theorems. Analysis of algorithms for random access machines with various measures of complexity; data structures such as heaps, priority queues, and balance trees; application of depth first search to graph algorithms such as biconnectivity and strong connectivity; sorting, recursion, dynamic programming, and introduction to reducibilities.

ICS611 (411) Programming Languages (g). Fall. Credit four hours. Prerequisite: ICS314 or consent of instructor. M W F 10:10.

An introduction to the structure of programming languages. Specification of syntax and semantics. Properties of algorithmic list processing and string manipulation languages: basic data types and structures, operations on data, statement types, and program structure. Macro languages and their implementation. Run-time representation of programs and data. Storage management techniques. Introduction to compiler construction.

ICS612 (412) Translator Writing (g). Spring. Credit four hours. Prerequisite: ICS611 or consent of instructor. M W F 1:25.

Discussion of the models and techniques used in the design and implementation of assemblers, interpreters, and compilers. Topics include lexical analysis in translators, compilation of arithmetic expressions and simple statements, specifications of syntax, algorithms for syntactic analysis, code generation and optimization techniques, bootstrapping methods, compiler-compiler systems.

ICS613 (413) Systems Programming and Operating Systems (g). Fall. Credit four hours. Prerequisite: ICS410 or consent of instructor. M W F 1:25.

The organization and software components of modern operating systems. Batch processing systems. Loaders, input-output systems, and interrupt handling. Descriptive schema for parallel processes; communication among parallel processes. Introduction to multiprogramming and multiprocessing systems. Addressing techniques, memory and instruction protection, procedure and data sharing; process scheduling, resource management; file organization, accessing, and management. Time-sharing systems. Case studies in multiprogramming, multiprocessing, and time-sharing. Job control languages and microprogramming. Projects involving the design and implementation of systems program modules.

ICS615 (415) Machine Organization (g). Spring. Credit four hours. Prerequisite: ICS314 or consent of instructor. M W F 2:30.

The design and functional organization of digital computers. Boolean algebra, elements of logical design, and computer components. Counters, shift registers, half and full adders, design of arithmetic units. Memory components, accessing and retrieval techniques, addressing structures, realization of indexing, and indirect addressing. Control unit structure, instruction decoding, synchronous and asynchronous control. Input-output channels, buffering, auxiliary memory structure, interrupt structures. Overall system organization, reliability, system diagnostics, system simulation.

ICS616 (416) Operations Research Models for Computer and Programming Systems (g). Spring. Credit four hours. Prerequisite: ICS611 and a course in probability (e.g., Mathematics BMA371 or IOD660) or consent of instructor. T Th 10:10; occasionally W 2:30.

Modeling and analysis of computer hardware and software systems. Some applications of the theories and techniques of operations research to problems arising in computer systems design and programming. Operating systems design: resource allocation and scheduling. Queuing models for time-sharing and multiprogramming systems. Reliability of computer systems and computer networks. Statistical techniques for measuring systems performance. Simulation of hardware and software; systems balancing. Applications of stochastic processes and inventory theory; e.g., file organization and management, models of computer center operation. Mathematical programming techniques applied to hardware configuration selection. Students will be expected to program and analyze a model which can be applied to a problem of hardware or software design.

ICS618 (517) Picture Processing (g). Spring. Credit four hours. Prerequisite: ICS611 or consent of instructor. M W F 10:10.

A study of computer graphics and digital picture analysis. Topics include display and digitization hardware, picture data structures, preprocessing and feature detection, the receptor-categorizer model of pattern recognition, linguistic methods in picture processing, mathematics of picture transformations, graphics programming languages and systems.

ICS621–622 (421–422) Numerical Analysis (g). Throughout the year. Credit four hours a term. Prerequisite: Mathematics BMA411 and knowledge of a programming language such as FORTRAN, ALGOL, or PL/I, or consent of instructor. M W F 9:05.

A more thorough treatment of the material of ICS321–322, at a faster pace, and covering additional topics. Emphasis on algorithms appropriate for use with computers.

ICS635 Special Topics in Information Retrieval (g). Fall. Credit four hours. Prerequisite: graduate standing, or ICS410 and consent of instructor. T 2:30–4:30.

Topics in the theories of indexing and classification. Use of algebraic and probabilistic models for the analysis of storage organizations and retrieval processes.

ICS641 (441) Mathematical Symbol Manipulation (g). Spring. Credit four hours. Prerequisite: ICS410 and some knowledge of discrete mathematics (e.g., ICS280, ICS481, or Mathematics BMA431). Hours to be arranged.

Arithmetic and algebraic algorithms and their implementation in a generalized computer system. The emphasis is on symbolic rather than numeric techniques for solutions to the problems. For each algorithm, computing times are derived and analyzed. Among topics are: infinite precision integer arithmetic, modular arithmetic, operations on multivariate polynomials and rational functions, such as symbolic integration and exact factorization over several fields, and exact solution of linear systems.

ICS681 (588) Theory of Algorithms and Computing I (g). Fall. Credit four hours. Prerequisite: ICS482 or consent of instructor. M W F 2:30.

An advanced treatment of topics related to ICS482, including computational models for random access machines, measures of complexity, analysis of algorithms, arithmetic complexity, lower bounds on complexity of practical problems, reducibilities, and polynomial complete problems. Algorithms discussed include fast Fourier transtorm, integer and polynomial arithmetic, evaluation and interpolation, external problems in graph theory, planarity, and triconnectivity.

ICS682 (587) Theory of Algorithms and Computing II (g). Spring. Credit four hours. Prerequisite: ICE481 or consent of instructor. M W F 2:30.

An advanced treatment of topics related to ICS481, such as axiomatic treatment of computability and computational complexity, including proofs from the axioms of certain theorems such as Rice's theorem, the speed-up theorems, and hierarchy theorems. Also an abstract account of formal languages (AFL's, principal AFL's, etc.) and algorithmic languages (program schemata, subrecursive languages, etc.). At the instructor's discretion the course will include such topics as structure of the polynomial degrees, universal schemata classes, Grzegorczyk hierarchy, equivalents of the LBA problem, classes of intractable problems, correctness of recursion rules, assignment of meaning to programs, natural unsolvable problems (word problems, Hilbert's 10th Problem, eqivalence of schemata, etc.), and investigations of time-space trade-off (Savitch languages, Cook's class, etc.).

ICS709 (591) Computer Science Graduate Seminar (g). Fall and spring. Credit one hour. For graduate students interested in computer science. Th 4:40–6. Staff, visitors, and students.

A weekly meeting for the discussion and study of important topics in the field.

ICS712 (487) Theoretical Aspects of Compiler Construction (g). Spring. Credit four hours. Prerequisite: ICS612 and ICS481. T Th 10:10.

Formal methods of syntactic analysis, including precedence, bounded context, and LR techniques. General parsing methods and their time-space complexity. Noncanonical parsing techniques. Two-level grammars. Formal methods of object code optimization. Methods of formal specification of the semantics of programming languages.

ICS719 (611) Seminar in Programming (g). Either term. Credit four hours. Prerequisite: ICS611 or consent of instructor. Th 2:30.

ICS721 (521) Solutions of Nonlinear Equations and Nonlinear Optimization Problems (g). Fall. Credit four hours. Prerequisite: ICS322 or consent of instructor. Hours to be arranged.

Emphasis on the rigorous analysis of practical numerical algorithms for nonlinear problems. Sample topics are nonlinear functional analysis, constrained and unconstrained minimization, and computationally convenient modifications of Newton's method, including quasi-Newton and penalty function methods and nonlinear least squares.

[ICS723 (523) Numerical Solution of Ordinary Differential Equations and Integral Equations (g). Fall. Credit four hours. Prerequisite: ICS322 or consent of instructor. Not offered in 1973–74.

Topics include solution of *n*th order nonlinear initial value problems and boundary value problems; single step methods; predictor-corrector techniques; stability, accuracy, and precision of methods; eigenvalue problems; solution of integral equations having constant or variable limits: finite difference and iterative methods; singular and nonlinear integral equations.]

ICS725 (525) Numerical Solution of Partial Differential Equations (g). Spring. Credit four hours. Prerequisite: ICS723 or consent of instructor. Hours to be arranged.

General classification; solution by method of characteristics; finite-difference methods for hyperbolic and elliptic equations; parabolic equations in two dimensions; direct solution of elliptic finite-difference equations; iterative methods for the solution of elliptic equations; block methods for large systems; singularities in elliptic equations; stability in relation to initial value problems and nonlinear discretization algorithms.

[ICS727 (527) Introduction to Approximation Theory (g). Fall. Credit four hours. Prerequisite: ICS322 or consent of instructor. Not offered in 1973–74.

The study of best approximations to functions. Topics include algorithms for best uniform and L_1 approximation by polynomials and rational functions, Padé approximation and continued fractions, the Kharshiladze-Lozinski theorems, and construction of subroutines for the evaluation of functions.]

ICS729 (621) Seminar in Numerical Analysis (g). Either term. Credit four hours. Prerequisite: consent of instructor. Hours to be arranged.

ICS739 (635) Seminar in Information Organization and Retrieval (g). Spring. Credit four hours. Prerequisite: ICS435. T 2:30–4:30.

ICS781 (488) Advanced Theory of Computing (g). Fall term of odd-numbered years. Credit four hours. Prerequisite: ICS682 or consent of instructor. M W F 10:10.

At the instructor's discretion, advanced results in automata theory, computability, and computational complexity. Topics may include noneffectiveness of speed-up, honest naming theorem for complexity classes, definition of operator complexity and reducibility classes, comparison of the power of programming languages, relationship between algorithmic languages and formal theories, equivalence algorithms for multi-tape finite automata, the computational complexity of decision problems (Presburger, Tarski's algorithms, etc.), and equivalents of the LBA problem (pebble automata and auxiliary pushdown automata).

[ICS782 (589) Advanced Topics in Algorithms (g). Spring term of odd-numbered years (1975, 1977, etc.). Credit four hours. Prerequisite: ICS682 or consent of instructor. M W F 10:10. Not offered in 1973–74.

At the instructor's discretion, advanced results in analysis of algorithms. Topics may include detailed analysis of complex algorithms, relationships between time and tape complexities, polynomial complete problems and reducibilities, complexity of decision problems, and recent results from the literature.]

ICS789 (681) Seminar in Automata Theory (g). Either term. Credit four hours. Prerequisite: consent of instructor. W 3:35.

ICS790 (590) Special Investigations in Computer Science. Either term. Prerequisite: consent of the registration officer of the department. Hours to be arranged.

Independent research.

ICS890 (590) Special Investigations in Computer Science. Either term. Prerequisite: consent of the registration officer of the department. Hours to be arranged.

Master's degree research.

ICS990 (590) Special Investigations in Computer Science. Either term. Prerequisite: consent of the registration officer of the department. Hours to be arranged.

Doctoral research.

Digital Systems Simulation (IOE680) (g). Fall. Credit three hours. Prerequisite: ICS314 and IOD670 or consent of instructor.

Switching Systems I (IEE675) (g). Fall. Credit three hours. Prerequisite: IEE316 or consent of instructor.

Switching Systems II (IEE676) (g). Spring. Credit three hours. Prerequisite: IEE675 or equivalent.

Electrical Engineering

The courses in electrical engineering are listed under the following headings: *Required Courses* (Systems Sequence; Electrophysics Sequence; Laboratory Sequence); *Elective and Graduate Courses* (Theory of Systems and Networks; Electronics; Power Systems and Machinery; Communications, Information, and Decision Theory; Computing Systems and Control; Radio and Plasma Physics and Electromagnetic Theory; General); and *Courses of Interest to Students in Other Curricula.*

Required Courses

Systems Sequence

IEE311 (4301) Analysis of Electrical Systems I (u). Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE210 and Mathematics BMA294 or equivalents.

Kirchhoff Laws and network equations, topological methods in circuit analysis. Concept of state; state analysis of linear systems. Transient and steady state response of networks to exponential excitations, impedance, and transfer functions. Properties of passive and active networks, introductory frequency domain circuit design and synthesis.

IEE312 (4302) Analysis of Electrical Systems II (u). Spring. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE311. G. Szentirmai.

Fourier series (response of linear systems to periodic excitation), Fourier integral (response of zero state linear systems to aperiodic excitation), the convolution integral (time domain response of linear systems), application to modulation methods, the single- and double-sided Laplace transform (complete response of linear systems). Time and frequency-domain relations.

IEE410 (4401) Random Signals in Systems (u). Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE312 or equivalent. H. S. McGaughan.

Description of random signals and analysis of randomly excited systems. An introduction to the concepts of probability, random variables, expectation, random processes, and power spectra. Applications are drawn from the areas of communications, control, and pattern classification. At the level of *Probability, Random Variables and Stochastic Processes* by Papoulis.

Electrophysics Sequence

IEE313–314 (4311–4312) Electromagnetic Fields and Waves (u). Fall and spring. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: Physics BPS233 and BPS234 and Mathematics BMA294, or equivalent.

Foundations of electromagnetic theory for static and dynamic fields, with applications to energy storage, propagation, and radiation. Topics will include Maxwell's equations, solution of electrostatic problems by separation of variables, Poynting's theorem; plane waves in isotropic dielectrics and conductors, energy in dispersive media, reflection and refraction of plane waves; transmission lines, waveguides, cavities; plane waves in anisotropic dielectrics; radiation and antennas. At the level of *Fields and Waves in Communication Electronics* by Ramo, Whinnery, and Van Duzer.

IEE411 (4411) Quantum Theory and Applications (u). Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE313–314 or equivalent. C. L. Tang.

Introductory quantum mechanics with particular emphasis on those concepts and results necessary for understanding modern solid state and qauntum electronic devices. The mechanics of the theory will be presented in terms of wave functions, operators, and solutions of Schroedinger's equation. Topics will include, for example, wave-particle duality, angular momentum, spin, particles in potential wells, and the hydrogen atom. Where possible, one-dimensional models will be used, but special features of two- and three-dimensional models will be discussed. Applications will include: tunnelling, electrons in periodic potential, density of states and energy bands in solids, periodic table, and atomic structure. At the level of *Basic Quantum Mechanics* by White.

Laboratory Sequence

IEE315 (4321) Electrical Laboratory I (u). Fall. Credit four hours. Two lectures, two laboratories. Prerequisite: IEE210.

Basic electrical and electronic instrumentation and measurements involving circuits and fields of both active and passive elements; an experimental introduction to solid state and high-vacuum devices; d.c. machines.

IEE316 (4322) Electrical Laboratory II (u). Spring. Credit four hours. Two lectures, two laboratories. Prerequisite: IEE311 and IEE313.

Laboratory studies of solid-state phenomena and devices; experiments illustrating the use of the digital computer in electrical engineering; laboratory studies of high-frequency phenomena and devices; an introduction to a.c. machinery.

Elective and Graduate Courses

Of the following elective and graduate courses, certain ones may not be offered every year if the demand is considered to be insufficient.

Theory of Systems and Networks

IEE420 (4450) Bioelectric Systems (u,g). Spring. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: Biological Sciences OBC423 or OBC427, or Physics BPS360, or IEE312. Consent of instructor required for laboratory. R. R. Capranica and M. Kim.

Application of electrical systems techniques to biological problems. Electrical activity of nerve cells; generation and propagation of nerve impulse; voltage clamp technique, Hodgkin-Huxley model, and its phase-plane analysis; electrical excitability and transfer function of neuromuscular systems; synaptic transmission; models of nerve cells and control system analysis of oscillatory activity. Nerve nets: evoked activity; spontaneous activity; simulation and computer analysis. Functional neuroanatomy of brain; transfer characteristics of sensory receptors; sensory encoding and processing in the peripheral and central nervous systems; neural mechanisms for vision and hearing.

IIE621 (4453) Introduction to Biomechanics, Bioengineering, Bionics, and Robots (u,g). (Same as Theoretical and Applied Mechanics IAH601). Fall. Credit three hours. Prerequisite: elementary differential equations, linear algebra, and probability; or consent of instructor. H. D. Block.

For course description, see Theoretical and Applied Mechanics IAH601.

IEE623 (4475) Active and Digital Network Design (u,g). Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: IEE312.

Introduction to network synthesis in terms of immittance and scattering parameters. Design of passive filters and matching networks. Active RC filter synthesis using negative-impedance converters (NIC), gyrators, and controlled sources.

State-variable synthesis techniques using operational amplifiers. Practical realizations of active RC filters and sensitivity considerations. Active 2-port network theory and design of transistor amplifiers (bipolar and FET). Negative-resistance amplifiers using tunnel diodes and varactors. Introduction to digital signal processing and discrete-time network design. Z-transform and the discrete Fourier transform (DFT). Design of nonrecursive and recursive digital filters. Realizations of digital processing algorithms by either software procedures or hardware implementations. The fast Fourier transform (FFT) algorithms. Topics for the optional laboratory session: design and construction of passive and active filters based on analytical and computer-aided techniques using available computer programs; transistor (bipolar and FET) amplifier design using measured scattering parameters; simulation and hardware implementation of digital filters; computational realizations of DFT and FFT algorithms.

IEE624 (4478) Computer Methods in Electrical Engineering (u,g). Spring. Credit four hours. Prerequisite: IEE312. Open to qualified juniors with consent of instructor. C. Pottle.

Designed to present modern techniques for solving electrical engineering problems on the digital computer. Efficiency (minimizing operation counts) and numerical stability rather than theoretical implications. Laboratory session used for experimenting with algorithms in an interactive environment. Solution of linear and nonlinear algebraic equations; finding eigenvalues and eigenvectors; root finding; interpolation and extrapolation; integration; solution of ordinary differential equations; random number generators. Parameter optimization. Computer hardware and software considerations in implementing algorithms. Applications to power systems, control systems, circuit design, semiconductor devices, communication systems.

IEE625 (4575) Computer Aided Network Design (u,g). Fall. Credit four hours. Three lectures. Prerequisite: IEE312. G. Szentirmai.

Frequency and time domain analysis of large linear circuits. State-variable and matrix techniques. D.C. and transient analysis of nonlinear circuits. Tolerancing and sensitivity calculations, adjoint network approach. General formulation of computerized design methods in time or frequency domains. Unconstrained and constrained optimization methods and computer programs. Modelling of circuits. Filter and active RC circuit synthesis methods. Methods of eliminating numerical sensitivity problems. Implementation of algorithms for cascading active and digital circuits.

IEE721 (4503) Theory of Linear Systems (g). Fall. Credit four hours. Three lectures. Prerequisite: IEE410, IEE312, and Mathematics BMA222; or consent of instructor. C. Pottle.

The state-space model for linear systems. Properties of ordinary linear differential equations. Fundamental and transition matrices. Matrix exponential functions, the Cayley-Hamilton theorem, and the Jordan form. Time invariant and time-varying network and system response. Controllability, observability, stability. Realizability of linear causal systems and applications of Fourier, Laplace, Hilbert transforms. Paley-Wiener theorem. Distributed systems. At the level of *Introduction to Linear System Theory* by Chen.

IEE722 (4504) Theory of Nonlinear Systems (g). Spring. Credit four hours. Three lectures. Prerequisite: IEE721 or IEE723 or consent of instructor.

Analysis of first- and second-order nonlinear systems with applications. Phase-plane analysis of autonomous systems; singular points, limit cycles, and equilibrium states; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; stability of nonlinear systems; the methods of Lyapunov and Popov; circle criteria. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically excited systems.

IEE723 (4571) Network Analysis (g). Fall. Credit four hours. Three lectures.

Introduction to network topology. Network formulation for computer-aided analysis. State-space techniques for time-invariant and time-varying networks. Scattering, immittance, hybrid formalisms. Nonreciprocal and active network properties. Scattering and realizability theorems for multiport networks. At the level of *Network Theory: An Introduction to Reciprocal and Non-Reciprocal Circuits* by Carlin and Giordano.

IEE724 (4572) Network Theory and Application (g). Spring. Credit four hours. Three lectures. Prerequisite: IEE721 or IEE723 or consent of instructor.

Physical basis for network techniques in lumped and distributed systems deduced from linearity, time invariance, and power-energy constraints. Generalized, bounded real and positive-real functions and matrices and the theory of physical realizability. Applications to insertion-loss synthesis, synthesis of n-ports, design of transmission line filters and equalizers. RC-lines. Gain-bandwidth theory of passive and active devices. Synthesis of active networks.

Electronics

IEE430 (4430) Introduction to Lasers and Optical Electronics (u,g). Spring. Credit four hours. Two lectures, one lecture-recitation, one laboratory. Prerequisite: IEE314, IEE411, or equivalents such as Applied Physics IPA355, IPA456, and Physics BPS443. G. J. Wolga and R. A. McFarlane.

An introduction to stimulated emission devices such as masers, lasers, and optical devices based on linear and nonlinear responses to coherent fields. Material discussed, based on quantum mechanical results, will employ phenomenological theories and will stress applications to modern devices. Subjects will include: propagation of rays, spherical waves, and gaussian beams; microwave and optical resonators and their field characteristics; interaction of matter and radiation; absorption and amplification; threshold for oscillation, rate equations, and output power; specific laser and maser systems; harmonic generation and optical mixing; modulators; parametric converters; detectors; elements of holography. Laboratory, to illustrate and elaborate on specific lecture material, will include: atom, ion, molecular, and solid state laser oscillators and their characteristics; mode properties of coherent optical fields; harmonic generation; optical mixing; optical communications link. At the level of *Introduction to Optical Electronics* by Yariv and *Introduction to Masers and Lasers* by Seigman.

IEE432 (4412) Solid State Physics and Applications (u,g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IEE441 or consent of instructor. J. Frey.

Introduction to solid state physics; applications to electronic devices. Classical concepts of solid-state physics, including crystal structure and symmetries, x-ray diffraction, Brillouin zone representation of periodic structures, band theory, phonon interactions, and superconductivity and relationship to the latest concepts and devices of electronic engineering. Some of the engineering problems discussed briefly in this context are the Gunn Effect for generation of microwaves, integrated circuit technology as dependent upon crystalline properties, the Josephson effect, and superconducting electric transmission lines. The interaction period is used for discussion of reading and lecture material, problem solution, and laboratory demonstration of some of the physical principles and engineering problems discussed in lecture. At the level of *Introduction to Solid State Physics,* 4th Edition, by Kittel.

IEE531–532 (4431–4432) Electronic Circuit Design (u,g). Fall and spring. Credit three hours a term. Two lectures, one laboratory. Prerequisite: IEE316. N. H. Bryant.

Design techniques for circuits used in electronic instrumentation. Circuits will be designed to provide specific functions, then constructed and tested in the laboratory. At the level of *Pulse Digital and Switching Waveforms* by Millman and Taub.

IEE631 (4433) Semiconductor Electronics I (u,g). Fall. Credit four hours. Three lectures, one laboratory. Prerequisite: IEE312, IEE316. P. D. Ankrum.

Band theory of solids; properties of semiconductor materials; the physical theory of p-n junctions, metal-semiconductor contacts, and p-n junction devices; device fabrication; properties of semiconductor devices such as diodes and rectifiers, light-sensitive and light-emitting devices, field effect and bipolar transistors, unijunction transistors, p-n-p-n devices (diodes, controlled rectifiers, and switches), etc.; device equivalent-circuit models; field-effect and bipolar transistor-amplifier stages. At the level of *Semiconductor Electronics* by Ankrum.

IEE632 (4434) Semiconductor Electronics II (u,g). Spring. Credit four hours. Three lectures, one laboratory. Prerequisite: IEE631. P. D. Ankrum.

A continuation of Semiconductor Electronics I. The application of semiconductor devices as active or passive elements in circuits for use as power supplies, power controls, amplifiers, oscillators, and multivibrators, pulse circuits, gates and switches, etc.; transistor noise; integrated circuits.

IEE633–634 (4437–4438) Solid State Microwave Devices and Subsystems I and II (u,g). Fall and spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IEE312 and IEE314 or equivalents. G. C. Dalman.

A theoretical and experimental study of modern solid state microwave devices and subsystems based on the Gunn Effect diode, IMPATT diode, TRAPATT diode, tunnel diode, p-n diode, and the transistor. Initially, the basic elements of microwave systems and subsystems such as microwave cavities, filters, oscillators, amplifiers, modulators, and detectors are studied, and then more complex elements such as microwave network analyzers, superheterodyne receivers, spectrum analyzers, noise measuring equipment, time domain reflectometers, and experimental Doppler Radars. Typical uses of solid state devices in these subsystems are discussed and analyzed. In many cases the subsystems themselves are used to characterize the circuit parameters of microwave solid state devices and other subsystems. An opportunity to study and operate a wide variety of modern test equipment such as the H.P. Network Analyzer, Sampling Oscilloscopes, near-carrier oscillator noise test sets, Spectrum Analyzers, and microwave laboratory test bench equipment. Participation in the design and testing of varactor tuned oscillators, low noise oscillators, Doppler Radar speed measuring devices, and other devices and subsystems of interest to the class. At the level of *Microwave Semiconductor Devices and Their Applications* by Watson.

IEE635 (4537) Integrated Circuit Technology (u,g). Fall. Credit three hours or four hours with project. Two lectures, one laboratory. Prerequisite: IEE411 or consent of instructor. J. Frey.

Integrated circuit techniques applicable in the fields of computer hardware, telecommunication systems, and opto-electronics are studied, with emphasis on device technology and the specialized approaches to device, circuit, and system design required by large-scale function integration. Computer logic and memory elements, both MOS and bipolar. Telecommunication applications include linear ICs and hybrid integration of microwave solid state devices, such as Gunn and IMPATT oscillators in transmitters and receivers. Integrated optics and compound semiconductor light-emitting and sensing devices. To illustrate the techniques discussed, each student fabricates planar silicon diodes or transistors in the microelectronics laboratory; project students later work on their own in the laboratory on topics of their choice, such as microwave integrated circuits, integrated gates, and opto-electronic devices. At the level of current papers in *IEEE J. Solid State Circuits* and *IEEE Trans. on Electron Devices.*

IEE636 Circuit Design for Integration (g). Spring. Credit three hours. Two lectures, one seminar-design laboratory. Prerequisite: IEE635 or equivalent. J. Frey.

Details of circuit design for integration in silicon monolithic integrated circuits and hybrid microwave integrated circuits will be discussed. The limitations of and the advantages afforded by the physics and technology of the processes involved in the fabrication of these circuits will be developed in relation to circuit design. Techniques for complete vertical integration of complex systems, from design through materials processing to final testing. Topics will include: component-dictated limitations on IC design; specialized functional blocks for linear and digital ICs; special components available to monolithic IC designers (e.g., multiple-collector transistors); feedback in linear IC design; chip layout; thermal considerations. The merging of design techniques for microwave integrated circuits and gigabit date rate digital ICs will also be discussed. The class will undertake a design/fabrication project. Device physics will be considered at the level of *Physics and Technology of Semiconductor Devices* by Grove; additional reading will be at the level of current papers in the *IEEE Journal of Solid State Circuits* and *Solid State Electronics.*

IEE731 (4531) Quantum Electronics I (g). Fall. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE313, IEE314, and Physics BPS443 or IEE411. G. J. Wolga.

A detailed treatment of the physical principles underlying optical masers, related fields, and applications. Topics will include: a review of quantum mechanics and the quantum theory of angular momentum; the interaction of radiation and matter; the quantum mechanical density matrix and macroscopic material properties; theory of the laser and maser. At the level of *Quantum Electronics* by Yariv and *Fundamentals of Quantum Electronics* by Pantell and Puthoff.

IEE732 (4532) Quantum Electronics II (g). Spring. Credit four hours. Three lectures, one recitation-computing session. Prerequisite: IEE731 or consent of instructor. R. A. McFarlane.

A continuation of the treatment of the physical principles underlying optical masers and related fields. Topics will include: optical resonators; output power of amplifiers and oscillators; dispersive effects and laser oscillation spectrum; Lamb theory; spectroscopy of atoms, molecules and ions in crystals as examples of laser media; survey of chemical and dye lasers; noise in optical devices; principles of electro-optic and parametric devices.

IEE733 (4533) Opto-Electronic Devices (g). Fall. Credit four hours. Three lectures, one recitation. Prerequisite: IEE411, IEE432, or equivalent. J. M. Ballantyne.

A variety of opto-electronic devices are considered with the aim of providing a physical understanding of some properties of solids which affect their use in optical devices. Topics include: a review of the macroscopic theory of electromagnetic waves in isotropic, lossy and anisotropic media; symmetry group theory of crystals; discussion of linear electrooptic devices such as modulators and deflectors; classical and quantum-mechanical treatment of the microscopic theory of dielectric constant and absorption in solids due to electronic transitions, including interband and intraband, impurity, surface state and exciton processes. The band-theory of photemission is discussed. Physics of hot and cold carrier transport, including effects of trapping, recombination, and scattering are treated, as is photoconductivity in solids and noise in optical detectors. Principles are illustrated by their application to the performance analysis of actual photoconductive, thermal, and photoemissive detectors. Other topics are treatment of gain and loss mechanisms in semiconductor lasers and light-emitting diodes and performance analysis of semiconductor lasers. Topics are mainly concerned with semiconductors, but metals and insulators are not excluded. At the level of *Dielectrics and Waves* by von Hippel, *Photoconductivity of Semiconductors* by Bube, *Physical Properties of*

Crystals by Nye, *Quantum Electronics* by Yariv, and *Optical Processes in Semiconductors* by Pankove.

IEE734 (4534) Theory and Applications of Nonlinear Optics (g). Credit four hours. Three lectures, one recitation. Prerequisite: IEE731 or IEE733 or the equivalent of Physics BPS572. C. L. Tang.

Recent developments in the theory and applications of nonlinear optics and related electrooptic devices. Topics include: properties and theories of nonlinear optical processes; nonlinear and electrooptic properties of III-IV and II-VI compounds and other optical materials; optical mixing; frequency up-conversion and down-conversion; spontaneous and stimulated processes involving nonlinear interactions of electromagnetic waves, phonons, and molecular vibrations; and electrooptical modulators, optical parametric oscillators, and other nonlinear optical devices. At the level of *Treatise in Quantum Electronics, Vol. I—Nonlinear Optics,* edited by Rabin and Tang, and current literature.

IEE735 (4535) Solid State Devices I (g). Fall. Credit four hours. Three lectures. Prerequisite: IEE432 or equivalent. C. A. Lee.

Properties of semiconductor devices, with emphasis on low-frequency operation (below 1000 GHz). Devices based on the tunnel effect: tunnel diodes, zener diodes, field emitter cathodes, thin film resistors. Devices based on charge flow across semiconductor-semiconductor contacts: p-n diodes, avalanche diodes, transistors, field effect transistors, unipolar transistors. Devices based on metal semiconductor contacts: Schottky diode, Schottky triode. Emphasis is placed on determining the factors underlying performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. Presented at the level of *Physics of Semiconductors* by Moll and of current papers published in the *IEEE Transactions on Electron Devices.*

IEE736 (4536) Solid State Devices II (g). Spring. Credit four hours. Three lectures. Prerequisite: IEE735 or equivalent. C. A. Lee.

Properties of semiconductor devices with emphasis on high frequency operation (above 1000 GHz). The approaches to the analysis to be studied are: ballistic analysis, electronic-network analysis, space-charge wave and coupled-mode analysis. Devices studied include avalanche microwave diode (Read diode), Gunn oscillators, fast response photo diodes, and other contemporary devices. Determination of the factors that underlie performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. Presented at the level of current papers published in the *IEEE Transactions on Electron Devices.*

[IEE737 (4631) Physics of Solid State Devices (g). Spring Credit two or three hours. Two lectures. Prerequisite: IEE736 or permission of instructor. Not offered in 1973–74.

Phenomena and problems associated with conduction in high electric fields, with emphasis on semiconductors. A review of hot electron phenomena, especially where instabilities arise because of multivalley band structure or other interaction of charge carriers with the host crystal. Basic theory of electron and hole scattering by phonons and examination of methods of obtaining distribution functions from the Boltzmann equation. Modifications required by complications of band structure.]

[IEE738 (4632) Physics of Solid State Devices (g). Credit two or three hours. Two lectures. Prerequisite: IEE737 or permission of instructor. Not offered in 1973–74.

Analysis of solid state devices of current interest (avalanche, LSA, Gunn devices, etc.) to give an understanding of some of the limitations involved in the design of such devices. Particular scattering mechanisms and band structure complications as factors in obtaining realistic distribution functions. Emphasis will be on analytical solutions because of the physical insight they afford, but numerical methods will be considered also. The number of devices considered will be limited, but subjects of specific interest to individuals can be considered on a seminar basis.]

Power Systems and Machinery

IEE551 (4441) Contemporary Electrical Machinery I (u,g). Fall. Credit three hours. Two lecture-recitations, one laboratory-computing session. Prerequisites: IEE312. R. E. Osborn.

Engineering principles. Real- and reactive-power requirements of core materials with symmetrical and biased magnetizing forces; analysis and characteristic prediction of high-efficiency transformers; magnetic amplifiers, energy transfers among electric circuits, magnetic fields and mechanical systems; control of magnetic field distribution by reluctance and winding distribution; traveling fields from polyphase excitation; elementary idealized commutator-type, asynchronous and synchronous machines.

IEE552 (4442) Contemporary Electrical Machinery II (u,g). Spring. Credit three hours. Two lecture-recitations, one laboratory-computing session. Prerequisite: IEE312. R. E. Osborn.

Engineering principles. Production of air-gap magnetic fields; elementary and idealized rotating machines; steady state and transient characteristics of realistic rotating machines; a-c commutator-type single-phase motors; polyphase synchronous and single-phase induction machines; recently developed types; Saturistor motor, self-excited a-c generators; miscellaneous rotary devices; Hysteresis motor, selsyns, amplidynes, frequency converters.

[IEE553 (4443) Power System Equipment (u,g). Fall. Credit three hours. Two lectures, one computing session. Prerequisite: IEE312. Not offered in 1973–74.

Engineering responsibilties for system equipment and control. Producer-user relations for catalog or built-to-order items. Calculations and test requirements of electrical apparatus for electrical power production, distribution, and use. Prime movers, generators and their accessories, switchgear, protective devices, power transformers, converters, towers, conductors, and regulating devices are analyzed. Inspections of nearby plants and equipment supplement classroom work.]

[IEE555 (4444) High-Voltage Phenomena (u,g). Spring. Credit three hours. Prerequisite: IEE312 or consent of instructor. Not offered in 1973–74.

Problems of the normal operations of power apparatus at very high voltages. The abnormal conditions imposed by lightning and the methods employed to assure proper operation. Laboratory testing of equipment under actual or simulated conditions. Dielectric behavior, traveling wave, and dielectric testing techniques. Electrical manufacturing test facilities are visited.]

IEE651 (4445) Electric Energy Systems I (u,g). Credit four hours. Three lecture-recitations, one computing session. Prerequisite: IEE316 and consent of instructor. S. Linke.

The physical and engineering principles underlying steady state operation and control of modern electric power systems, with emphasis on the characteristics of major power-system parameters. Theory of electromechanical energy converters, power transformers, conventional transmission lines and cables, power networks, and other power-system components; use of the digital computer as a dynamic "laboratory" model of a complex power system for load-flow studies. Laboratory-computing periods will include selected experiments with small electromechanical energy converters. At the level of *Elements of Power System Analysis* (2nd ed.) by Stevenson.

IEE652 (4446) Electric Energy Systems II (u,g). Credit four hours. Three lecture-recitations, one computing session. Prerequisite: IEE651. S. Linke.

Continuation of principles presented in Electric Energy Systems I. Transient behavior of power networks. Theory of unbalanced systems, symmetrical components, protective relaying systems, power-system stability, high-voltage–direct-current systems and economic dispatch; use of the digital computer for fault studies and economic analysis. At the level of *Elements of Power System Analysis* (2nd ed.) by Stevenson.

Communications, Information, and Decision Theory

IEE661 (4473) Coding Algorithms (u,g). Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: some knowledge of linear algebra. For the laboratory, Fortran, PL/I, or Assembly language programming.

Coding algorithms for compression and storage of information, for correction of errors in digital data processing and transmission, and for synchronization. Design, analysis, and implementation of underlying codes. Linear block codes, convolutional codes, maximum likelihood and sequential decoding, linear sequential machines, cyclic codes. Bose-Chaudhuri codes, burst error protection, threshold decoding, variable length source coding. Laboratory consists of demonstrations and projects involving design and computer simulation, modification, and evaluation of coding algorithms covered in lecture. At the level of *An Introduction to Error Correcting Codes* by Lin.

IEE662 (4474) Fundamental Information Theory (u,g). Spring. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: IEE410 or equivalent knowledge of probability. Prerequisite for laboratory only: IEE661.

Fundamental results of information theory and their application to information storage, compression, processing, and transmission. The basis of modern design of digital communication systems. Source coding, properties of entropy, and other information measures. Signal selection and detection aspects of noisy transmission channels. Channel capacity and Shannon's coding theorems. Analysis of sequential decoding. Fidelity criteria and rate-distortion functions. Communication over Gaussian channels. Laboratory projects investigate through computer simulation the statistical problems involved with information source and channel characterization and approximation (quantization), and evaluate the advantages and limitations of the various coding algorithms introduced in IEE661. At the level of *Information Theory* by Ash.

IEE663 (4476) Statistical Aspects of Communication (u,g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IEE410 or equivalent. H. S. McGaughan.

Analysis of analog and digital communication systems in the presence of random signals and noise. System optimization, matched filters, linear smoothing, and prediction of stationary processes. Modulation systems, performance of analog systems in time and frequency multiplex with additive noise; digital modulation systems, PCM systems with additive noise. Design of signals for digital transmission. Receiver optimization, design of decision oriented receivers, error bounds; selected topics in hypothesis testing and parameter estimation applied to receiver design.

IEE664 Decision Making in Pattern Classification (u,g). Spring. Credit three or four hours (three hours with ten and ½ weeks of lectures; four hours with either ten and ½ weeks of lectures and laboratory or fourteen weeks of lectures.) Prerequisite: IEE410 or IEE761 or equivalent course in probability. P. Bergmans.

Concepts and key results of decision theory will be developed and applied to problems of pattern classification (hypothesis testing). Typical pattern classification problems include classification of hand-written, typed, or printed alphanumeric charcaters; the transcription of speech; identification of regions in photographs; and medical diagnosis. Formulations of the design of pattern classification systems will be examined under a variety of assumptions concerning prior information about the pattern source and the objectives in constructing such a system. The design philosophies to be discussed include those of minimum expected loss, Neyman-Pearson, and minimax risk and regret. Laboratory projects will require the computer-based design and simulation of a pattern classifier for a real or simulated pattern source.

IEE761–762 (4507–4508) Random Processes in Electrical Systems (g). Fall and spring. Credit four hours. Three lectures.

The concepts of randomness and uncertainty and their relevance to the design and analysis of electrical systems. An exiomatic characterization of random events. Probability measures, random variables, and random vectors. Distribution functions and densities. Functions of random vectors. Expectation and measures of fluctuation. Moment and probability inequalities. Properties and applications of characteristic functions. Modes of convergence of sequences of random variables: laws of large numbers and central limit theorems. Kolmogorov consistency conditions for random processes. Poisson process and generalizations. Gaussian processes. Covariance-stationary processes, correlation functions, spectra; Bochner and Wiener-Khinchin theorems. Continuity, integration, and differentiation of sample functions. Hilbert space approach of optimum filtering and prediction. Spectral representation, orthogonal series representations. Markov chains and processes. Linear and nonlinear transformations of random processes.

IEE763 (4674) Advanced Topics in Information Theory (g). Fall. Credit four hours. Three lectures. Prerequisite: IEE662 and either IEE761 or Mathematics BMA571, or consent of instructor. T. Berger.

An in-depth treatment of an information theory research area. The topic varies from year to year and will be chosen from the following subjects: Source encoding (rate distortion theory), convolutional codes and sequential decoding, multiterminal communication networks, ergodic theory and information in abstract spaces, and complexity and instrumentability of coding schemes.

IEE764 (4672) Foundations of Inference and Decision Making (g). Spring. Credit three hours. Three lectures. Prerequisite: a course in probability and some statistics, or consent of instructor.

Much advanced research in information processing and its applications involves sources about which we have very little knowledge and the use of performance criteria of doubtful adequacy. This motivates an examination of methods for characterizing uncertainty and chance phenomena and for transforming information into decisions and optimal systems. Discussion of the foundations of inference centers on various approaches to the interpretation and formalization of probability, including the following: axiomatic systems of comparative probability; Kolmogorov system of quantitative probability; relative frequency interpretations; computational complexity, randomness, and probability; classical probability and invariance; logical probability and induction; subjective probability and personal decision making. The discussion of the foundations of decision making will center on utility theory, axiomatic rationality, statistical decision theory, the nature of a good system, and recent work on system design when there is little prior information.

[IEE765 (4673) Principles of Analog and Digital Communications (g). Spring. Credit four hours. Three lectures. Prerequisite: IEE762 or consent of instructor. Not offered in 1973–74.

The fundamentals of information theory, signal theory, and statistical estimation and decision theory are used to formulate approaches to the solution of problems arising in digital and analog communication. Particular topics are: receiver and signal design, probability of error, capacity, threshold effects for the additive Gaussian channel. Extensions to the additive Gaussian channel; feedback, random gain and phase, diversity. Time-variant Gaussian channels; receiver and signal design, probability of error, and capacity. At the level of *Principles of Coherent Communication* by Viterbi.]

Computing Systems and Control

IEE671–672 (4481–4482) Feedback Control Systems (u,g). Fall and spring. Credit three hours (four hours with laboratory). Prerequisite: IEE312 or consent of instructor.

The analysis of feedback control systems and synthesis techniques to meet specifications or minimize performance indices. Mathematical models of physical systems and solution of differential equations by the Laplace Transform; transfer functions. The state-space approach to control systems; observability, controllability. Analysis and synthesis of linear control systems by root locus and frequency response methods. Nonlinearities in control systems; analysis and compensation using describing functions and the phase plane; Lyapunov stability. Sampled-data systems and digital compensation. An introduction to parameter optimization and optimal control. Laboratory work consists of familiarization with system components and correlation of transient and frequency responses; synthesis of linear and optimal control systems and analysis of nonlinear and sampled-data systems using analog and digital computers.

IEE673 (4483) Hybrid Computation I (u,g). Fall. Credit four hours. Two lectures, one laboratory. Prerequisite: IEE312 or an equivalent background with consent of instructor. N. M. Vrana.

Basic concepts and principles of hybrid computation as applied to problems in engineering analysis, simulation, and design; analog computation and the design of special-purpose patchable logic programs that are used to support analog computation; the digital computer in a hybrid environment. Laboratory work with general-purpose analog computers, patchable logic systems, and the PDP-11/TR-48 hybrid computer system. At the level of *Analog and Digital Computer Methods in Engineering Analysis* by James, Smith, and Wolford.

IEE674 (4484) Hybrid Computation II (u,g). Spring. Credit four hours. Two lectures, one laboratory. Prerequisite: IEE673. N. M. Vrana.

Theory, design, characteristics and programming of hybrid computer systems; analog-digital computer linkage systems; error analysis and error compensation in hybrid computation; theory and laboratory work on automatic iterative procedures, steepest-descent programs, parameter optimization and identification, and the maximum principle. The laboratory work will be with the PDP-11/TR-48 and the AD-40 hybrid computers. At the level of *Hybrid Computation* by Bekey and Karplus.

IEE675 (4487) Switching Circuits and Logic Design (u,g). Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: Mathematics BMA293–294 or equivalent.

Switching devices, Boolean algebra; function minimization and decomposition; adders and other combinational circuits; number representation and codes; synchronous and asynchronous sequential circuits; circuit equivalence; secondary assignments; counters and shift registers; fault detection and diagnosis. Topics for optional laboratory session: design and construction with MSI modules of counters, shift registers, adders and other arithmetic circuits in digital computers. At the level of *Switching Circuits: Theory and Logic Design* by Torng.

IEE676 (4488) Computer Structures (u,g). Spring. Credit three hours or four hours with laboratory. Thee lectures, one laboratory. Prereqisites: IEE675 or Computer Science ICS314, or consent of instructor.

Architecture and design of computing systems; configuration of components; memory organization; central processing unit design; microprogramming; input-output management; channel controller; interrupt; performance evaluation. Topics for optional laboratory session; design and implementation of small-scale, general-purpose or special-purpose calculators and computers. At the level of *Computer Structures: Readings and Examples* by Bell and Newell.

IEE771 (4505) Estimation and Control in Descrete Linear Systems (g). Fall. Credit four hours. Three lectures. Prerequisite: IEE410 or consent of instructor. J. S. Thorp.

Optimal control, filtering and prediction for discrete time linear systems with extensive use of the APL/360 system. Approximation on discrete point sets, curve fitting with various error measures. Modelling of discrete time systems with applications to tracking and estimation problems. Optimal control of discrete time linear systems, the principle of optimality. Optimal filtering and prediction for discrete time linear systems, Kalman filtering. Stochastic optimal control, the separation principle. No knowledge of a programming language is assumed: the APL language will be learned during the term through use of a library of programs written for the course. At the level of *Stochastic Optimal Linear Estimation and Control* by Meditch.

IEE772 (4506) Optimal Control and Estimation for Continuous Systems (g). Spring. Credit four hours. Three lectures. Prerequisite: IEE771 or consent of instructor. J. S. Thorp.

Methods of design problem formulation, computational techniques, and mathematical background are developed for the implementation of continuous optimal control and estimation.

Deterministic and stochastic controls as well as unbiased estimators are formulated on both finite and infinite time intervals. Extensive examples are given such as re-entry vehicle flight-control, rocket-booster guidance, aircraft tracking, and human operator simulation. Methods of successive approximation and substitution are presented for minimization with respect to parameters and functions, with and without equality and inequality constraints. Properties of Lyapunov and Riccati equations are discussed. Material is illustrated by the student use of an APL library of computer programs for the automated design of continuous controls and estimators.

[IEE773 (4681) Random Processes in Control Systems (g). Spring. Credit four hours. Three lectures. Prerequisite: IEE762 and IEE772. Not offered in 1973–74.

Prediction and filtering in control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, generalized Wiener filtering, stochastic optimal and adaptive control problems. Selected topics: Bayes decision rule, min-max policy, maximum likelihood estimate, control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; stability of control systems with random parameters.]

Radio and Plasma Physics and Electromagnetic Theory

IEE581 (4461) Wave Phenomena in the Atmosphere (u,g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: IEE312 and IEE314.

An elementary treatment of wave phenomena in the atmosphere of the earth, including gravity waves, planetary waves, acoustic waves, radio waves, and plasma waves; attention is directed to the role of these phenomena in various atmospheric processes and engineering problems such as weather, diffusive transport, air-sea interaction, radio communication, and remote sensing.

IEE582 (4462) Radio Engineering (u,g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: IEE314 and IEE410.

Electrical systems for communications, control, detection, and other purposes in which radiowaves play a central role: system functions, including generation, modulation, transmission, reception, and demodulation; guidance, radiation, and propagation of radiowaves, including transmission lines and waveguides, antenna systems, and the effects of atmospheric inhomogeneity; system design problems.

[IEE680 (4464) Elementary Plasma Physics and Gas Discharges (u,g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: IEE314 or equivalent. Not offered in 1973–74.

Review of electromagnetic wave theory and applications. Gas discharges and arcs: positive column, collisions, mobility, diffusion, breakdown, sheaths, DC and RF excitation, transition from glow to arc, Langmuir and conductance probes, reflex discharge, effects of magnetic field. Plasma as a dielectric medium, interaction of electromagnetic waves (e.g., microwaves) with plasma in free space and finite regions. Plasma oscillations, space-charge waves, cyclotron harmonic radiation, Tonks-Dattner resonances, effects of plasma temperature. At the level of *Plasma Diagnostics with Microwaves* by Heald and Wharton.]

IEE681 (4561) Introduction to Plasma Physics (u,g). (Same as Applied and Engineering Physics IPE606). Fall. Credit three hours. Three lectures. Prerequisite: IEE313 and IEE314 or equivalent. Open to fourth-year students at discretion of instructor.

Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles, and microscopic instabilities; test particle in a plasma; elementary applications. At the level of *Elementary Plasma Physics* by Longmire.

IEE682 (4564) Advanced Plasma Physics (u,g). (Same as Applied and Engineering Physics IPE607). Spring. Credit three hours. Three lectures. Prerequisite: IEE681.

Boltzmann and Vlasov equations; moments of kinetic equation, Chew-Goldberger-Low theory, waves in hot plasmas, Landau damping, instabilities due to anisotropies in velocity space, gradients in magnetic field, temperature and density, effects of collisions and Fokker-Planck terms; high-frequency conductivity and fluctuations, quasi-linear theory; neoclassical toroidal diffusion, relativistic beams.

IEE683 (4511) Electrodynamics (g). Fall. Credit four hours. Three lectures, one recitation. Prerequisite: IEE312 and IEE314, or equivalent.

Foundations of electromagnetic theory. Maxwell's equations, electromagnetic potentials, and integral representations of the electromagnetic field. Special theory of relativity. Radiation of accelerated charges and Cerenkov radiation. Electrodynamics of dispersive and anisotropic media. Normal modes of waveguides and cavities. Surface waves and leaky waves. At the level of *Theory of Electromagnetism* by Jones.

IEE684 (4514) Microwave Theory (g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IEE312 and IEE314, or equivalent.

Theory of passive microwave devices. Waves in homogeneous and inhomogeneous waveguides; propagation and distortion of pulses; application of gyrotropic media to nonreciprocal waveguide devices. Scattering matrix analysis of multiport junctions, resonant cavities, directional couplers, isolators, circulators. Periodic waveguides. Elastic waves in solids and their microwave applications. At the level of *Introduction to the Theory of Microwave Circuits* by Kurokawa.

IEE685–686 (4551–4552) Upper Atmosphere Physics I and II (u,g). Fall and spring. Credit three hours each term. Three lectures. Prerequisite: IEE314. D. T. Farley.

The physical processes governing the behavior of the earth's ionosphere and magnetosphere. Topics will include diagnostic measurement techniques; production, loss, and transport of charged particles in the ionosphere and magnetosphere; temperature variations; airglow; tidal motions, winds, and gravity waves in the ionosphere; the electrical conductivity of the ionosphere, the dynamo-current system, and the equatorial and auroral electrojets; plasma instabilities in the ionosphere; interactions between the ionosphere, magnetosphere, and solar wind; acceleration and drift of energetic particles in the magnetosphere; precipitation of particles and the aurora; magnetic and ionospheric storms. At the level of *Introduction to Ionospheric Physics* by Rishbeth and Garriott.

[IEE687 (4565) Radiowave Propagation I (u,g). Fall. Credit three hours. Three lectures. Prerequisite: IEE314 and IEE410 or equivalent. Not offered in 1973–74.

Propagation in the earth's environment: troposphere, ionosphere, magnetosphere, and interplanetary space. Diffraction and surface wave propagation; tropospheric refraction and ducting; propagation in the ionospheric plasma, including magnetoionic theory, the CMA diagram, cross modulation and Faraday rotation, whistler mode propagation, ion effects and ion whistlers, group velocity and ray tracing. WKB solutions of the coupled-wave equations.]

[IEE688 (4566) Radiowave Propagation II (u,g). Spring. Credit three hours. Three lectures. Prerequisite: IEE687 or equivalent. Not offered in 1973–74.

Full-wave solutions of the coupled-wave equations; interactions between particles and waves in the magnetosphere; radar astronomy; the scattering of radio waves from random fluctuations in refractive index; tropospheric and D region ionospheric scatter propagation; incoherent scatter from the ionosphere and its use as a diagnostic tool; radio star and satellite scintillations and their use in studying the ionosphere and solar wind.]

[IEE781 (4661) Kinetic Theory (g). (Same as Applied and Engineering Physics IPG761). Spring, every other year. Credit three hours. Two lectures. Prerequisite: Physics BPS561, BPS562, or permission of instructor. R. L. Liboff. Not offered in 1973–74; will be offered spring term 1975.

Designed for students wishing a firm foundation in fluid dynamics, plasma-kinetic theory, and nonequilibrium statistical mechanics. Brief review of classic dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analysis of the BBKGY sequence. Master equation, density matrix, Wigner distribution. Derivation of fluid dynamics. Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Klimontovich formulation. Kubo theory. Coarse graining and ergodic theory. At the level of *Introduction to the Theory of Kinetic Equations* by Liboff.]

IEE782 Nonlinear Phenomena in Plasma Physics (g). Spring. Credit three hours. Corequisite: IEE682. E. Ott.

Nonlinear processes in plasmas and their implications for such diverse fields as controlled thermonuclear fusion and space plasmas. (1) Coherent nonlinear processes (echoes, trapped particles, solitary waves, shocks, and parametric instabilities); (2) statistical theories of plasma turbulence (quasilinear theory, wave kinetic equations, the random phase approximation, resonant mode-mode coupling, nonlinear Landau damping, Dupree's theory of strong plasma turbulence, anomalous resistivity and diffusion, and turbulent heating.) At the level of current articles in *Physics of Fluids* and *Journal of Experimental and Theoretical Physics (Soviet Physics).*

General

IEE591–592 (4591–4592) Project (u,g). Fall and spring. Credit three hours.

Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing his project; an engineering report on the project is required.

IEE691–692 Special Topics in Electrical Engineering (u,g). Credit one to three hours.

Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

IEE791–792 (4691–4692) Electrical Engineering Colloquium (g). Fall and spring. Credit one hour per term. For graduate students enrolled in the Field of Electrical Engineering.

Lectures by visiting authorities, staff, and graduate students. A weekly meeting for the presentation and discussion of important current topics in the field.

IEE793–794 (4595–4596) Electrical Engineering Design (g). Fall and spring. Credit three hours per term. Offered for students enrolled in the M.Eng. (Electrical) degree program.

Utilizes real engineering situations to present fundamentals of engineering design.

IEE795–799 (4700–4800) Special Topics in Electrical Engineering (g). Credit one to three hours.

Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

Courses of Interest to Students in Other Curricula

IEE210 (4210) Introduction to Electrical Systems (u). Either term. Credit three hours. Three lecture-recitations. Prerequisite: Mathematics BMA192 and Physics BPS112.

A core-science course intended to develop competence in several analysis skills appropriate to the field of electrical engineering and to impart understanding of the physical basis for the concepts associated with the skills. Topics include: electrical circuit elements (resistors, capacitors, inductors, independent sources, and branch relationships); time functions and their representation (real exponentials, complex numbers, trigonometric functions, and complex exponentials); response of simple networks and the impedance concept (natural response, forced response to periodic excitation, and pole zero concepts); circuit equations and methods of solution (branch equations, Kirchhoff's laws, nodal and mesh equations, matrix methods of solution, and Norton and Thevenin equivalents); controlled sources and modeling of devices (representation of idealized electronic and electromechanical devices).

Engineering Physics

See p. 68.

Environmental Engineering

See p. 77.

Geological Sciences

The courses in Geological Sciences are listed under the following headings: *Freshman and Sophomore Courses; Junior, Senior, and Graduate Courses;* and *Field Courses.*

Freshman and Sophomore Courses

IGE101 (101) Introductory Geological Science (u). Fall. Credit three hours. Lectures, T Th 9:05 or 11:15. Two scheduled preliminary examinations will be held at 7:30 p.m. during the term. Laboratory, M T W Th or F 2–4:25, S 10:10–12:35, T 7:30–10 p.m. Field trips. W. B. Travers and staff.

Designed to give students a comprehensive understanding of earth processes, features, and history. Basic knowledge for more specialized courses or a major in geological sciences. Study of the earth, particularly materials, structure, internal condition, and the physical and chemical processes at work. Principles of interpretation of earth history, evolution of continents, oceans, mountain systems, and other features; development of its animal and plant inhabitants.

IGE102 (102) Introductory Geological Science (u). Spring. Credit three hours. Prerequisite: IGE101. Lectures, T Th 11:15. Two scheduled preliminary examinations will be held at 7:30 p.m. during the term. Laboratory, M T W Th or F 2–4:25, S 10:10–12:35, T 7:30–10 p.m. Field trips. J. M. Bird and staff.

A continuation of IGE101.

IGE103 (111) Earth Science (u). Fall. Credit three hours. (See Earth Science Laboratory IGE105.) Lectures, M W F 9:05. D. E. Karig.

Physical geography, including the spatial relationships of the earth, moon, and sun that determine the figure of the earth, time, seasons, atmospheric and oceanic circulation, and climates.

IGE105 (113) Earth Science Laboratory (u). Fall. Credit one hour. To be taken concurrently with IGE103. Laboratory, W or Th 2–4:25. D. E. Karig.

Observation and calculation of daily, monthly, and seasonal celestial events; topographical mapping and map interpretation; world climatic regions.

IGE131 (203) Geology and the Environment (u). Fall. Credit three hours. Lectures, T Th 9:05. Laboratory, T W or Th 2–4:25. Field trips. G. A. Kiersch.

The principles of geological science, with emphasis on the physical phenomena and rock properties as they influence the natural environments of man. Laboratory analysis of the cause and effect of geological problems encountered in the planning, construction, and operation of man's works, and the influence of environmental factors.

IGE162 (212) Mineral Resources (u). Spring. Credit three hours. Lectures, M W F 9:05. B. Bonnichsen and W. B. Travers.

Utilization of and man's dependence upon mineral resources; their nature, occurrence, distribution, and availability at home and abroad. Political and economic aspects of their availability and control.

IGE172 (202) Ancient Life (u). Spring. Credit three hours. No prerequisite, but IGE102 is desirable. Lectures, M W F 11:15. J. L. Cisne.

A cultural course devoted to a review of the fossil remains of life in the geologic past as the main basis of the concept of organic evolution. Vertebrate forms from fish to man.

IGE232 (214) Environmental Geology (u). Spring. Credit three hours. Prerequisite: IGE101, IGE103, or IGE131. Lectures, M W 11:15. Laboratory and discussion periods, T W or Th 2–4:25. Field trips. G. A. Kiersch.

The geologic basis of man's environment and its significance in our modern technology. Discussion sections with laboratory problems, field trips, and a term project.

Junior, Senior and Graduate Courses

Of the following, the core courses IGE325, IGE345, IGE355–356, IGE376, and IGE388 may be taken by those who have successfully completed IGE101–102 or the equivalent, or who can demonstrate to the instructor that they have adequate preparation in mathematics, physics, chemistry, biology, or engineering.

Core Courses

IGE325 (325) Structural Geology and Sedimentation (u). Spring. Credit four hours. Suggested prerequisite: IGE355 or consent of instructor. Lectures, M W F 10:10. Laboratory, T 2–4:25. W. B. Travers.

Nature, origin, and recognition of geologic structures. Behavior of geologic materials, stresses, geomechanical and tectonic principles applied to the solution of geologic problems. Analysis of structural features by three-dimensional methods. Introduction to the sedimentary and hydraulic processes and petrology of sedimentary rocks. Description, classification, provenance, transportation, and depositional environment of sediments. The relationship between sedimentary structures, clay mineralogy, and prelithification deformation as indications of regional tectonic history. Compaction and diagenesis of sediments.

IGE344 (444) Geological Oceanography (u,g). Spring. Credit three hours. Prerequisite: IGE102 or Biological Sciences OBG461. Lectures, M W F 9:05. Training cruise, depending on ship availability.

Shoreline erosion, transportation, and deposition; origin and structure of continental shelves and ocean basins. Geologic processes and geomorphic development in the marine environment.

IGE345 (345) Geomorphology (u). Fall. Credit four hours. Prerequisite: IGE102 or consent of instructor. Lectures, T Th 9:05. Laboratory, T 2–4:25. Additional assigned problems. A. L. Bloom.

Description and interpretation of land forms in terms of structure, process, and stage.

IGE355 (355) Mineralogy, Petrology, and Geochemistry I (u). Fall. Credit four hours. Prerequisite: IGE102 or consent of instructor. Lectures, T Th 10:10. Laboratory, M 2–4:25. Assigned problems and readings. Field trips. B. Bonnichsen.

Megascopic and optical properties, chemistry, and petrogenetic significance of rock-forming minerals. Principles of phase equilibria as applied to igneous and metamorphic systems. Description, classification, chemistry, petrography, origin, and regional distribution of igneous and metamorphic rocks. Geochemical distribution of trace elements and isotopes in igneous and metamorphic systems. Study of representative rock suites from various igneous and metamorphic terranes.

IGE356 (356) Mineralogy, Petrology, and Geochemistry II (u). Spring. Credit four hours. Lectures, T Th 10:10. Laboratory, M 2–4:25. Assigned problems and readings. Field trips. B. Bonnichsen.

A continuation of IGE355.

IGE376 (376) Historical Geology and Stratigraphy (u). Fall. Credit four hours. Lectures, T Th 9:05. Laboratory, W Th 2–4:25. Additional assigned problems. J. L. Cisne.

Application of geologic principles to interpretation of earth history; development of the geologic column, geochronology, and geochronometry; correlation and the zone concept; sedimentary environments and provinces; geosynclines and platforms; problems of the pre-Cambrian and continental evolution.

IGE388 (388) Geophysics and Geotectonics (u). Spring. Credit four hours. Prerequisite: Mathematics BMA112 and Physics BPS208 or equivalent. Lectures, M W F 10:10. Laboratory, to be arranged. B. L. Isacks and J. E. Oliver.

Global tectonics and the deep structure of the solid earth as revealed by investigations of earthquakes, earthquake waves, the earth's gravitational and magnetic fields, and heat flow.

Emphasis on the integration of geophysical observations with the theory of plate tectonics.

Advanced Courses

IGE423 (423) Petroleum Geology (u,g). Fall. Credit three hours. Suggested prerequisite: IGE325. Lectures, M W F 1:10. Laboratory, M 2–4:25. Field trip. W. B. Travers.

Sedimentation and tectonics as conditions of hydrocarbon entrapment. Problems of petroleum exploration, including geophysical investigations, subsurface mapping, the movement of underground fluids, and the geophysical properties of subsurface fluids and sediments. The organization and operation of the petroleum industry; on-shore and off-shore exploration and production techniques. Future petroleum provinces, particularly in the off-shore region, and case histories of selected oil fields.

IGE424 (424) Tectonics of Continental Margins (u,g). Spring. Credit three hours. Offered in alternate years. Suggested preliminary courses: IGE101–102, IGE325, and a course in petrology. Lectures, M W F 11:15. W. B. Travers.

The deformation history of selected continental margins and shallow seas. Methods of investigation, geophysical drilling, and dredging. The role of ocean-floor spreading, ocean trenches, and large ocean-floor faults in the tectonics of continental margins.

[**IGE426 (426) Regional Tectonics (u,g).** Spring. Credit three hours. Offered in alternate years. Suggested preliminary courses: IGE101–102, IGE325, and a course in petrology. Field trips. W. B. Travers. Not offered in 1973–74.

The growth of mountains as illustrated by the history, composition, and deformation style of selected mountain ranges. Examination of mountain building in relation to rigid plate tectonics, particularly ocean trenches. Discussion of volcanism and plutonism as mountain-building processes.]

IGE436 (436) Rock Deformation (u,g). Spring. Credit three hours. Prerequisite: IGE325. Lectures, M W F 1:10. G. A. Kiersch.

Review of stress analysis and behavior of materials, both the rock mass and sample. Fundamentals of deformation pertaining to the crustal rocks and the problems of geological sciences.

IGE461 (461) Mineral Deposits: Metals (u,g). Fall. Credit four hours. Prerequisite: IGE356 or consent of instructor. Lectures, M F 10:10. Laboratory, F 2–4:25. Assigned problems and readings. Field trip. B. Bonnichsen.

Description, origin, distribution, and economic significance of the principal types of metallic ore deposits. Principles and processes involved in the formation of metallic ore deposits within the context of their geologic environments. Megascopic and microscopic identification of principal opaque ore minerals; hand-sample and microscopic study of representative ore and rock suites from various mining districts.

IGE462 (462) Mineral Deposits: Nonmetals (u,g). Spring. Credit four hours. Prerequisite: IGE461 or consent of instructor. Lectures, M W F 10:10. Laboratory, F 2–4:25. Field trips. Staff.

Properties, occurrence, associations, distribution, and economic utilization of the industrial minerals and rocks.

IGE471 (471) Invertebrate Paleontology (u,g). Fall. Credit four hours. Prerequisite: IGE102 and, if possible, invertebrate zoology. For those interested in fossil evidence of the development of organisms. Lectures, T Th 10:10. Laboratory, W Th 2–4:25. J. L. Cisne.

Paleobiology and classification of important fossil invertebrates.

IGE485 (485) Physics of the Earth I (u,g). Fall. Credit three hours. Open to upperclass engineers, majors in the physical sciences, and others by permission of instructor. A. F. Kuckes.

Rotation and figure of the earth, gravitational field, seismology, geomagnetism, creep and anelasticity, radioactivity, earth's internal heat, continental drift, and mantle convection.

IGE486 (486) Physics of the Earth II (u,g). Spring. Credit three hours. Open to upperclass engineers, majors in the physical sciences, and others by permission of instructor; Physics of the Earth I is not required. A. R. Seebass.

Composition and structure of the atmosphere and oceans, radiative balance, heat budget, dynamics of the oceans and atmosphere, tides, geostrophic motions and thermal wind, Rossby waves and cyclogenesis, internal waves and seiches.

IGE490 (490) Senior Thesis (u). Either term. Credit one hour. Staff.

IGE632 (582) Exploration Geology (g). Spring. Credit three hours. Prerequisite: field geology and, usually, graduate standing. Lectures, M W 9:05. Laboratory, W 2–4:25. G. A. Kiersch.

Methods of exploration and appraisal of geologic data from both field and laboratory investigations. Assessment of environmental geology and the presentation of direct and indirect information for professional purposes.

IGE633 (533) Environmental/Engineering Geology: Theory (g). Fall. Credit three hours. Prerequisite: IGE325; IGE355–356 and IGE345 recommended. Lectures, M W 11:15. Laboratory, M 2–4:25. Field trips. G. A. Kiersch.

Advanced study of physical phenomena and rock properties of special importance from the planning through the operation stages of engineering works and in man's environment; includes underground fluids, subsidence, gravity movement, seismicity, geomechanics and stresses, rock mechanics, weathering, and geologic materials of construction. Analysis of geologic problems encountered in practice; predicting the influence of natural and man-made environmental factors.

IGE635 (535) Engineering Geology: Practice (g). Fall. Credit three hours. Offered in alternate years. Prereqiusite: IGE633 or IGE325, IGE355–356, and IGE345. Lectures, M W 9:05. Laboratory, T 2–4:25. Field trips. G. A. Kiersch.

Application of geological principles in the planning-design, construction, and operation of engineering works. Case histories, analysis, and evaluation of physical environmental factors, remedial treatment, and reports.

[IGE642 (542) Glacial and Pleistocene Geology (g). Spring. Credit three hours. Prerequisite: IGE345 or consent of instructor. Lectures, T Th 9:05. Laboratory, T 2–4:25. Several Saturday field trips. A. L. Bloom. Not offered in 1973–74.

Glacial processes and deposits and the stratigraphy of the Pleistocene.]

[IGE673 (573) Stratigraphy (g). Fall. Credit three hours. Offered in alternate years. Prerequisite: IGE376. Lectures, T Th 9:05 and one hour to be arranged. J. L. Cisne. Not offered in 1973–74.

Principles of stratigraphy, developed by detailed study of selected American and European systemic examples.]

IGE681 (521) Geotectonics (g). Fall. Credit four hours. Prerequisite: consent of instructor. Lectures, T Th 11:15–1:15. J. M. Bird.

Theories of orogeny; ocean and continent evolution. Kinematics of lithosphere plates. Rock-time assemblages of modern oceans and continental margins, and analogs in ancient orogenic belts. Time-space reconstructions of specific regions. Problems of dynamic mechanisms—corollaries and evidence from crustal features.

IGE687 (587) Seismology (g). Fall. Credit three hours. Prerequisite: Mathematics BMA421, BMA422, BMA423, or equivalent. Lectures, T Th 9:05 and one hour to be arranged. B. L. Isacks and J. E. Oliver.

Theories of generation and propagation of elastic waves in the earth. Derivation of the structure of the earth and the mechanisms of earthquakes from seismological observations.

IGE688 (588) Gravity, Geomagnetism, and Heat Flow (g). Spring. Credit three hours. Prerequisite: Mathematics BMA421, BMA422, BMA423, or equivalent. Lectures, T Th 9:05 and one hour to be arranged. D. E. Karig.

Measurement and mathematical description of the gravitational and magnetic fields of the earth; heat flow; gravitational, magnetic, and heat flow anomalies and the structure of the earth; theories of the origin of the geomagnetic field. Selected advanced topics.

IGE690 (690) Seminars and Special Work (g). Throughout the year. Credit two hours a term. Prerequisite: consent of instructor.

Advanced work on original investigations in geological sciences.

IGE690-a Structural geology, sedimentation, and tectonics. W. B. Travers.
IGE690-b Petrology and geochemistry of metamorphic and igneous rocks, associated metallic minerals. B. Bonnichsen.
IGE690-c Coastal geomorphology and Pleistocene geology. A. L. Bloom.
IGE690-d Environmental/engineering geology, geomechanics, and hydrogeology. G. A. Kiersch.
IGE690-e Geophysics, seismology, gravity, magnetism, heat flow, geotectonics. B. L. Isacks and J. E. Oliver.
IGE690-f Invertebrate paleontology and paleoecology. J. L. Cisne.
IGE690-g Mineral deposits and resources. Staff.
IGE690-h Environmental problems. W. B. Travers.
IGE690-i Marine geology. D. E. Karig.
IGE690-j Plate tectonics and geology. J. M. Bird.

Field Courses

IGE601 (701) Intersession Field Trip (u,g). Credit one hour. Prerequisite: IGE101–102 or equivalent and consent of instructor. G. A. Kiersch.

A trip of one week to ten days in an area of interesting geology in the lower latitudes. Travel and subsistence expenses to be determined. Interested students should contact the instructor during the early part of the fall semester.

IGE602 (702) Introductory Field Geology (u,g). Spring. Credit one hour. Prerequisite: one introductory course or IGE325, and consent of instructor. Four weekend trips and two laboratory meetings. Times to be arranged. W. B. Travers.

Techniques of field mapping will be learned by examining selective localities in southern New York and vicinity. Techniques will include use of the Brunton compass, detailed field descriptions of various rock types, the identification and field use of fossils, and the description of land forms. The students will make detailed and regional geologic maps, construct cross sections and columnar sections, and make observations on the environment of deposition or conditions of emplacement of rocks and describe their subsequent geologic history.

Industrial Engineering and Operations Research

Undergraduate Courses

IOA213 (9113) Systems Analysis and Design (u). Spring. Credit three hours. Two lectures, one recitation. Prerequisite: Mathematics BMA293. T. Berger.

Introduction to the modeling of systems, using the concepts of states and transitions. Formulation of models common to problems in various branches of engineering. Use of graph theory, difference equations, and Markov chains to analyze and design static and dynamic systems.

IOA260 (9160) Introductory Engineering Probability (u). Either term. Credit three hours. Three lectures. Prerequisite: first year calculus. L. I. Weiss and staff.

Affords students a working knowledge of some of the basic tools in probability theory and their use in engineering. This may be the last course in probability for some students, or it may be followed by a course in probability or statistics. The topics include: a definition of probability; basic rules for calculating with probabilities when the number of possible outcomes is finite; discrete and continuous random variables; probability distribution and density functions; expected values, jointly distributed random variables, and marginal and conditional distributions; special distributions important in engineering work; the normal, exponential, binomial, Poisson, and other distributions, and how they arise in practice; and Markov chains and applications.

IOA270 (9170) Basic Engineering Statistics (u,g). Either term. Credit three hours. Two lectures, one recitation. (Graduate students will be assigned to a separate recitation section.) Prerequisite: first year calculus. Staff.

Affords students a working knowledge of basic statistics as it applies to engineering work. For students who wish to learn more about statistics, a course in probability (e.g., IOA260) followed by a course in statistics (e.g., IOC370) are recommended. The topics are: graphical and numerical methods of representing data—histograms and cumulative frequency polygons, sample means and variances; basic tools of probability, discrete and continuous random variables, probability distribution and density functions, expected values and "population" moments, special distributions—the normal, chi-square, binomial, and others; tests of "significance" and one-sided and two-sided hypothesis tests concerning the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; point- and confidence-interval estimation; correlation and curve fitting by least squares.

IOA335 (9135) Introduction to Game Theory (u). Spring. Credit three hours. Three lecture-recitations. L. J. Billera.

A broad survey of the mathematical theory of games, including such topics as two-person matrix and bimatrix games; cooperative and non-cooperative n-person games; games in extensive, normal, and characteristic function form. Economic market games. Structure theory for games arising from complex organizations.

IOC301 (9301) Introduction to Systems Engineering (u). Fall. Credit three hours. Three lecture-recitations. B. W. Saunders.

An introduction to modern systems engineering concepts. Historical development of industrial engineering, the emergence of operations research techniques, and the maturing of classical industrial engineering into the more universal systems engineering methodology. Industrial organizations and their functions of production, marketing, costing, etc.; parallels drawn with their counterparts in health-care systems, governmental systems, and other service industries to demonstrate the universality of systems methodology.

IOC320–321 (9320–9321) Optimization Models and Methods in Industrial Engineering and Operations Research I–II (u). Fall: IOC320; four hours credit; three lectures, one recitation. Spring: IOC321; three hours credit; two lectures, one recitation. Prerequisite: Mathematics BMA293 and the rudiments of computer programming and probability (as presented in IOA260). M. J. Todd.

Formulation, analysis, and solution of classes of optimization models arising in industrial engineering and operations research. Modeling of resource allocation, production planning, distribution, inventory, location, investment, and engineering design problems. Determination of objectives and decision alternatives. Properties and solution techniques for models described in terms of the following dichotomies: deterministic-probabilistic, univariate-multivariate, constrained-unconstrained, linear-nonlinear, discrete-continuous, static-dynamic, and single-multiple decision makers. Methodologies include the simplex method, gradient techniques, recursive procedures, heuristics, etc. Synthesis of IE/OR techniques; interplay between formulation and solution.

IOC335 (9335) Introduction to Game Theory (u). Spring. Credit four hours. Four lecture-recitations. Prerequisite: IOC320 or IOE622. L. J. Billera.

The same topics as IOA335; lectures will be common for both courses. Registrants in IOC335 will have separate recitations requiring the indicated prerequisites.

IOC350 (9350) Cost Accounting, Analysis, and Control (u). Either term. Credit four hours. Three lecture-recitations, one computing session. R. N. Allen.

Accounting theory and procedures, financial reports; product costing in job-order and process-cost systems—historical and standard costs; cost characteristics and concepts for analysis, control, and decision making; differences between accounting and engineering objectives in the development and uses of cost data. Capital budgeting, investment planning, and introduction to decision making based on economic criteria.

IOC361 (9361) Probabilistic Models in Industrial Engineering and Operations Research (u,g). Spring. Credit four hours. Three recitations, one computing session. Prerequisite: IOA260 or equivalent. S. C. Jaquette.

Basic probabilistic techniques will be developed and applied in engineering problem areas. Topics to be covered include: transform methods (particularly the z-transform and the Laplace transform); the Poisson process with extensions; the general birth-death process; a variety of queuing and inventory models. Theoretical background and derivations will be included to make clear the assumptions and limitations of the models and to introduce the student to the problems of formulation of analogous models found in engineering and operational situations.

IOC370 (9370) Introduction to Statistical Theory with Engineering Applications (u). Either term. Credit four hours. Three lectures, one recitation. Prerequisite: a course in probability (e.g., IOA260). T. J. Santner and L. I. Weiss.

Provides a working knowledge of basic statistics as it is most often applied in engineering work, and a basis in statistical theory for continued study and further application. A variety of statistical procedures are presented, together with the theoretical principles on which they are based. May be followed by IOE512 or IOC371 or by Industrial and Labor Relations 311 or Statistics and Biometry 511. Topics include a review of distributions of special interest in statistics: normal, chi-square, binomial, Poisson, t and F; introduction to statistical decision theory and Bayes procedures; basic principles underlying hypothesis tests: the Neyman-Pearson theory; one- and two-sided hypothesis tests of the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; basic principles of point and confidence interval estimation; minimum variance unbiased estimators, maximum likelihood estimation; confidence-interval estimates of the mean and variance of a normal distribution; the bivariate normal distribution and correlation; linear regression and curve fitting by least squares.

IOC371 (9371) Applications of Statistics to Engineering Problems (u). Fall. Credit four hours. Three lectures, one recitation. Prerequisite: IOC370 or equivalent. Staff.

Applications of regression and correlation techniques to problems arising in engineering and the sciences. Introduction to design and analysis of experiments. Elementary nonparametric procedures. Single-stage, two-stage, and sequential sampling rules.

IOC383 (9383) Applications of Computer Science in Industrial Engineering and Operations Research (u,g). Spring. Credit four hours. Two lectures, one computing session. Prerequisite: IOA260, IOC370, and Computer Science ICS211. D. G. Severance.

The application of computers in the anaysis of industrial engineering and operations research problems. Simulation methodology. Design of data processing systems for operational control. Use of statistical and mathematical programming packages.

IOC410 (9310) Industrial Systems Analysis (u). Fall. Credit four hours. Three lectures, one computing session. Prerequisite: IOC350 and IOC370 or equivalent. H. P. Goode.

Selected methods of industrial systems analysis such as those needed in problem definition, evaluation, systems design and control, and operational decision making. The application of probability, statistics, and cost theory to typical problem situations. Network problems, reliability, and replacement situations will be discussed.

IOC411 (9311) Industrial Systems Design (u). Spring. Credit four hours. Two lectures, one computing session. Prerequisite: IOC410. H. P. Goode.

The design of complex man-machine systems and the methods and procedures required for their operational control. Measures of system feasibility, effectiveness, and sensitivity. Problems of system experimentation will be introduced.

Much of the work will be done through specific design problems.

IOC437 (9337) Dynamic Programming (u). Fall. Credit four hours. Four lecture-recitations. Prerequisite: IOC320 or IOE622 and IOA260. G. L. Nemhauser.

Will have common letcures with IOE637 but will include one extra recitation.

Graduates Courses

IOD660 (9460) Introduction to Probability Theory with Engineering Applications (u,g). Fall. Credit four hours. Three lectures, one recitation. R. F. Serfozo.

Covers the same topics as IOA260, but all lectures and computing sessions are independent of those for IOA260.

IOD670 (9470) Introduction to Statistical Theory with Engineering Applications (u,g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: IOA260 or IOD660. H. M. Taylor 3d.

Covers the same topics as IOC370, but all lectures and computing sessions are independent of those for IOC370.

IOE512 (9512) Statistical Methods in Quality and Reliability Control (u,g). Spring. Credit three hours. Three lectures. Prerequisite: IOC370 or equivalent. H. P. Goode.

Control concepts: control methods for attributes and variables; process capability analysis; attributes acceptance sampling plans and procedures; double and multiple sampling plans; elementary procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability applications; life and reliability analysis of components; analysis of series and parallel systems; stand-by and redundancy; elementary sampling-inspection procedures used for life and reliability.

[**IOE613 (9513) Systems Engineering (g).** Spring. Credit three hours. Two recitations, one laboratory. Elective for graduate students and qualified undergraduates. Prerequisite: IOC320 and IOC370 or consent of instructor. Not offered in 1973–74.

Methods of describing, analyzing, and manipulating complex, interrelated open systems. Graphical and mathematical analysis. Techniques of design of transportation, service, and information systems and appropriate evaluation methods.]

IOE614 (9514) Facilities Location and Design (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOC320 or IOE622 or consent of the instructor. P. M. Dearing.

Location and facility design models with various objective functions and under different feasibility assumptions. Mathematical programming techniques are used to develop theory and methods of solution for the models discussed. Applications in industrial and environmental engineering, regional planning, and economics.

IOE621 (9521) Production Planning and Control (g). Spring. Credit four hours. Three lectures. Prerequisite: IOC320 and IOC361 or consent of instructor. W. L. Maxwell.

Methods for the planning and control of large-scale operations, with emphasis on manufacturing systems. Sales and production forecasting; manufacturing planning; routing, scheduling, and loading; sequencing; dispatching; planning and control of inventories. Mathematical, statistical, and computer methods for performing these functions.

IOE622 (9522) Operations Research I (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: consent of instructor. Not open to students who have had IOC320. S. Stidham, Jr.

Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, nonlinear programming, dynamic programming, introduction to inventory theory; game theory, comprehensive problems, and case studies.

IOE623 (9523) Operations Research II (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOA260, IOA270, or permission of the instructor. Not open to students who have had IOE626. P. M. Dearing.

Models for inventory and production control. Replacement theory; queuing, including standard birth and death process model and nonstandard models; application of queuing theory. Simulation. Illustrative examples and problems.

IOE626 (9526) Mathematical Models—Development and Application (g). Fall. Credit four hours. Three lecture-recitations, one computing session. Prerequisite: IOC320 and IOC361 or equivalent. P. M. Dearing.

Examination of probabilistic and deterministic models in relation to industrial engineering work. The function of models and their usefulness in analysis, synthesis, and design. Application of various models, their modification to fit special circumstances, and the development of new models to describe particular conditions or situations. Markov chains and dynamic programming.

[**IOE627 (9527) Traffic Flow Theory (g).** (Same as Civil and Environmental Engineering IIF640). Spring. Credit three hours. Two lectures.

Prerequisite: IOA260 or consent of instructor. Not offered in 1973–74.

Study of various mathematical theories of traffic flow. Microscopic models (car following models). Macroscopic models (kinematic wave theory). Stochastic properties of traffic flow at low density. Probability models for traffic lights and optimal control of signalized intersections. Traffic flow on transportation networks. Application to traffic assignment. Traffic networks simulation system.]

IOE637 (9537) Dynamic Programming (u). Fall. Credit three hours. Three lecture-recitation periods. Prerequisite: IOA260 or IOD660; IOC320 is desirable. G. L. Nemhauser.

Optimization of sequential or multistage decision processes based upon the application of the dynamic programming principle of optimality. Theory, computation, and applications.

IOE640–741 (9540–9541) Network Flows and Extremal Combinatorial Problems I–II (g). Fall: IOE640. Spring: IOE741. Credit three hours a term. Three lecture-recitation periods. Prerequisite: consent of instructor; first term is prerequisite to the second. D. R. Fulkerson.

The theory of flows in capacity-constrained networks and related areas in applied combinatorial mathematics. Topic include: maximum flow, feasibility criteria, minimum path, mnimum cost flow, maximum dynamic flow, out-of-kilter algorithm, multi-terminal flows, network synthesis, project cost curves, scheduling problems, set representatives, (0,1)-matrices, matchings, packing and covering problems, matroid partition and intersection, flows in infinite graphs, blocking systems, frames, block and and anti-blocking pairs of polyhedra.

IOE660 (9560) Applied Stochastic Processes (g). Spring. Credit four hours. Three lectures, one recitation. Open to qualified undergraduates. Prerequisite: a good first course in probability (e.g., IOD660 or Mathematics BMA371), or a similar degree of sophistication (e.g., IOA260 plus IOC361). S. Stidham, Jr.

An introduction to stochastic processes; a variety of applications of the basic theory. Topics are: second order processes; Markov chains and processes; diffusion processes, renewal theory and recurrent events; fluctuation theory; random walks; branching processes; Brownian motion; birth and death processes. Examples are drawn from queuing theory, population growth and other ecological models, inventory theory, etc.

IOE662 (9562) Inventory Theory (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: IOC361 and permission of instructor. S. C. Jaquette.

An introduction to the mathematical theory of inventory and production control; the construction and solution of mathematical models. Topics will be drawn from the recent technical literature and will include deterministic and stochastic demands; dynamic programming and stationary analysis of inventory problems; renewal theory applied to inventory problems; multiechelon problems; statistical problems; and production smoothing.

IOE670 (9570) Intermediate Statistics (g). Fall. Credit four hours. Three lectures, one recitation. Prerequisite: IOC370, IOD670, or permission of instructor. T. J. Santner.

Distributions used in the analysis of the properties of standard statistical tests, including noncentral F distributions. Power of standard statistical tests. Distributions of estimators. Rational choice of sample size. Simple, multiple, and partial correlation. Regression analysis. Tests of goodness of fit.

[IOE671 (9571) Design of Experiments (g). Spring. Credit four hours. Three lectures. Prerequisite: IOE670 or permission of instructor. Not offered in 1973–74.

Use and analysis of experimental designs such as randomized blocks and Latin squares; analysis of variance and covariance; factorial experiments; statistical problems associated with finding best operating conditions; response-surface analysis.]

IOE672 (9572) Statistical Decision Theory (g). Spring. Credit three hours. Three lectures. Prerequisite: IOC370 and IOE670, or equivalent. L. I. Weiss.

The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules. Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function and other nonparametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement.

IOE680 (9580) Digital Systems Simulation (g). Fall. Credit four hours. Two lectures, one recitation. Required of M.Eng. (Industrial) students. Prerequisite: Computer Science ICS211 and IOC370, or permission of instructor. W. L. Maxwell.

The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program; synchronization and file maintenance, random-number generation, random-deviate sampling. Programming in simulation languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process.

IOE682 (9582) Data Processing Systems (g). Spring. Credit four hours. Two lectures, one computing session. Prerequisite: Computer Science ICS211 or permission of instructor. R. W. Conway.

The design of integrated data-processing systems for operational and financial control; questions of system organization, languages, and equipment appropriate to this type of application; file structures, addressing, and search problems, sorting techniques; problems of multiple-remote-input, on-line data-processing systems; techniques of system requirement analysis.

IOE690 (9590) Special Investigations in Industrial Engineering and Operations Research (u,g). Either term. Credit and sessions as arranged. Offered to students individually or in small groups. Registration must be made with the registration officer of the School.

Study, under direction, of special problems in the Field of Industrial Engineering and Operations Research.

[IOE725 (9525) Scheduling Theory (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: consent of instructor. Not offered in 1973–74.

Scheduling problems; problem definition and performance measures. Single resource scheduling. MxN scheduling problems. Priority queuing approaches. Simulation of jobshop dispatching and heuristic procedures.]

IOE730 (9530) Mathematical Programming (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: advanced calculus and basic linear algebra, or IOC320–321. L. J. Billera.

The dual theorem of linear programming. Geometric and algebraic characterizations of the problem. Adjacent extreme point methods including degeneracy. Data organization for computation. Post-optimality analysis. Transportation and other network programming problems. Primal-dual and decomposition methods. Introduction to two-person games and to integer, nonlinear, and stochastic programming.

[IOE731 (9531) Integer Programming (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOE730. Not offered in 1973–74.

Discrete optimization. Linear programming problem in which the variables are restricted to be integers. Theory, computation, and applications.]

IOE732 (9532) Nonlinear Programming (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOE730. M. J. Todd.

Necessary and sufficient conditions for unconstrained and constrained optima. Computational methods, including interior (e.g., penalty functions), boundary (e.g., gradient projection), and exterior (e.g., cutting plane) approaches.

[IOE733 (9533) Combinatorial Analysis (g). Spring. Credit three hours. Three lecture-recitations. Not offered in 1973–74.

Incidence systems such as block designs, finite geometries, and other combinational designs, counting and enumeration techniques, combinatorial extremum problems, matroids, coding theory, selected topics in graph theory.]

IOE734 (9534) Graph Theory (g). Spring. Credit three hours. Three lecture-recitations. W. F. Lucas.

Finite, infinite, directed, undirected, combinatorial, and topological graphs. Connectedness, planarity and inbedding problems, enumeration problems, coloring and matching problems, automorphism group of a graph, generalizations of graphs, matrix methods, network problems. Applications to electrical networks, economics, and sociometry.

[IOE735–736 (9535–36) Game Theory I–II (g). Fall: IOE735. Spring: IOE736. Credit three hours a term. Three lecture-recitations. Prerequisite: Mathematics BMA411 or consent of instructor; first term is prerequisite to the second. Not offered in 1973–74.

Two-person-zero-sum games; the minimax theorem, relationship to linear programming. Two-person-general-sum games. Noncooperative *n*-person games; Nash equilibrium points. Cooperative *n*-person games: the core, stable sets, Shapley value, bargaining set, kernel, nucleolus. Games without side payments. Games with infinite numbers of players. Economic market games. Mathematical techniques of game theory.]

[IOE738 (9538) Game Theory Seminar (g). Spring. Credit three hours. Prerequisite: IOE736 or consent of instructor. Not offered in 1973–74.

A seminar in which students read and report on current papers of interest in game theory, primarily in the area of *n*-person cooperative theory.]

IOE739 (9539) Selected Topics in Mathematical Programming (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: IOE730 and consent of instructor. L. J. Billera.

Current research topics in mathematical programming.

IOE761 (9561) Queuing Theory (g). Fall. Credit three hours. Three lectures. Prerequisite: IOD660 and permission of instructor. R. F. Serfozo.

Definition of a queuing process. Poisson and Erlang queues. Imbedded chains. Transient behavior of the systems M/G/1 and GI/M/1. The general queue GI/G/1. Bulk queues. Applications to specific engineering problems such as shop scheduling, equipment maintenance, and inventory control.

[**IOE765 (9565) Time-Series Analysis (g).** Fall. Credit three hours. Three lectures. Prerequisite: permission of instructor. Not offered in 1973–74.

The Hilbert space projection theorem and its application to linear prediction and linear statistical inference. Spectral representations of wide sense stationary processes. Estimation of spectral densities and other topics in empirical spectral analysis. Discussion of several time-series models and the basic statistical techniques associated with the models.]

IOE769 (9569) Selected Topics in Applied Probability (g). Either term. Credit three hours. Three lectures. Prerequisite: IOE660 and permission of instructor. H. M. Taylor 3d.

Selected topics in applied probability for advanced students. Topics will be chosen from current literature and research areas of the staff.

[**IOE773 (9573) Statistical Multiple-Decision Procedures (g).** Fall. Credit three hours. Three lectures. Prerequisite: IOE671 or permission of instructor. Not offered in 1973–74.

The study of multiple-decision problems in which a choice must be made among two or more courses of action. Statistical formulations of the problems. Fixed-sample size, two-stage, and sequential procedures. Special emphasis on applications to ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Recent developments.]

IOE774 (9574) Nonparametric Statistical Analysis (g). Spring. Credit three hours. Three lectures. Prerequisite: IOD670 or permission of instructor. L. I. Weiss.

Estimation of quantiles, c.d.f.s. and p.d.f.s. Properties of order statistics and rank-order statistics. Hypothesis testing in one- and two-sample situations. Large-sample properties of tests and asymptotic distributions of various test statistics.

[**IOE779 (9579) Selected Topics in Statistics (g).** Either term. Credit three hours. Three lectures. Prerequisite: IOE670 or permission of instructor. Not offered in 1973–74.

Selected topics chosen from such fields as nonparametric statistical methods, sequential analysis, multivariate analysis.]

IOE789 (9589) Selected Topics in Information Processing (g). Fall. Credit four hours. Two lectures, one computing session. Prerequisite: Computer Science ICS314 and IOE682, or permission of instructor. D. G. Severance.

Selected topics in the design and optimization of record storage and file accessing methodology using operations research techniques.

IOE791 (9591) Operations Research Graduate Seminar (g). Fall and spring. Credit one hour each term. Staff.

A weekly 1½ hour seminar devoted to presentation, discussion, and study of research in the Field of Operations Research. Distinguished visitors from other universities and institutions, both domestic and foreign, and faculty members and advanced graduate students of the Department and the University speak on topics of current interest.

IOE793–794 (9593–9594) Industrial Engineering Graduate Seminar (g). Fall and spring. Credit one hour each term.

A weekly meeting to discuss assigned topics and hear presentations of the state of the art from practitioners in the field.

IOE898–899 (9598–9599) Project (g). Fall and spring. Credit variable. A normal requirement of eight credit hours must be completed by each candidate for the professional Master's degree during the last two terms of matriculation.

Project work requires the identification, analysis, and design of feasible solutions to some loosely structured systems engineering problem. The solution must be defended on sound engineering and economic grounds.

Materials Science and Engineering

Undergraduate Courses

ITK331 (6031) Structure and Properties of Materials (u). Fall. Credit four hours. Lectures and laboratory.

Techniques for characterizing materials. Theory and practice of optical microscopy, x-ray and electron diffraction, transmission and scanning electron microscopy. Crystal structure and symmetry, amorphous and semicrystalline materials, polymers. Quantitative metallography, characterization of microstructure. Relation of structure to properties.

ITK333 (6033) Research Involvement I (u). Fall. Credit three hours.

Semi-independent research project in affiliation with a faculty member and research group of the Department. Approval of Department required.

ITK334 (6034) Research Involvement II (u). Spring. Credit three hours.

May be continuation of ITK333, or a one-term affiliation with a research group. Approval of Department required.

ITK335 (6035) Thermodynamics of Condensed Systems (u). Fall. Credit three hours. Three lectures.

Introduction to basic thermodynamic laws from classical and statistical viewpoints. Multicomponent systems; concept of chemical potential. Heterogeneous equilibrium, phase diagrams. Phase transformations, solutions.

ITK336 (6036) Kinetics, Diffusion, and Phase Transformations (u). Spring. Credit three hours. Three lectures.

Introduction to absolute rate theory, atomic motion, and diffusion. Applications to nucleation and growth of new phases in vapors, liquids, and solids; solidification, crystal growth, oxidation and corrosion, radiation damage.

ITK339 (6039) Materials Engineering (u). Fall. Credit three hours. Two lectures, one laboratory (alternate weeks).

Selection and processing of materials for engineering applications. The effect of processing on the structure and properties of materials and the control of properties by variations in processing. Processing methods considered involve solidification, plastic deformation, heat treatment, material bonding, and consolidation of powders.

ITK440 (6040) Macro-Processing of Materials (u). Spring. Credit three hours. Three lectures, occasional laboratory.

Control of chemical composition through smelting, reaction, and refining processes; applications to iron and steel, aluminum, refractories, etc. Shape control; casting and solidification, welding; mechanical shaping through rolling, drawing, etc. Deformation and annealing, textures; relation to material properties. Thermomechanical treatments for control of material properties.

ITK441 (6041) Micro-Processing of Materials (u). Fall. Credit three hours. Three lectures, occasional laboratory.

Materials aspects of electronic and magnetic device components. Crystal growth, including composition control. Zone refining. Thin film, vapor deposition, sputtering, and ion implantation techniques. Diffusion and integrated circuit technology. Composite materials.

ITK443–444 (6043–6044) Senior Materials Laboratory (u). Either term. Credit three hours.

Experiments are available in structural studies, properties of materials, deformation and plasticity, mechanical and chemical processing, phase transformations, surface physics, etc.

ITK445 (6045) Electrical and Magnetic Properties of Materials (u). Fall. Credit three hours. Three lectures.

An introduction to electrical and magnetic properties of materials with emphasis on structural aspects. Classification of solids; charge and heat transport in metals and alloys; semiconductors and insulators; principles of operation and fabrication of semiconductor devices; behavior of dielectric and magnetic materials; phenomenological description of superconducting materials.

ITK446 (6046) Mechanical Properties of Materials (u). Spring. Credit three hours. Three lectures.

Elasticity theory; stress, strain, equilibrium. Plastic flow under combined stresses, yield surfaces. Experimental techniques, photoelasticity, etc. Plastic flow, creep, and fatigue. Fracture mechanics. Relation to material structure.

ITK448 (6048) Current Topics in Materials (u). Spring. Credit three hours. Three lectures.

Coordinated lectures on topics of current interest, such as biomaterials, fuel cells, composite materials, materials problems in power generating and distribution systems, stress corrosion cracking, etc.

ITA201 (6101) Elements of Materials Science (u). Spring. Credit three hours.

Relations between atomic structure and macroscopic properties of such diverse materials as metals, ceramics, and polymers. Properties discussed include magnetism, superconductivity, insulation, semi-conductivity, mechanical strength, and plasticity. Applications to microelectronics, desalinization by reverse osmosis, superconducting power transmission lines, synthetic bones and joints, etc. Extensive use of modern educational techniques, including slides, audiotutorial systems, movies, student response system.

ITB261 (6261) Introduction to Mechanical Properties of Materials (u). Either term. Credit three hours. Two lectures, one recitation or laboratory.

Elastic, anelastic, and plastic behavior of crystalline and rubber-like materials; single and polycrystalline materials. Stress-thinning mechanisms, composite materials; fracture, fatigue, and creep. Crystal structure, lattice defects, phase equilibria, diffusion, macrostructure and microstructure from programmed learning sequences. Engineering applications of materials.

ITB262 (6262) Introduction to Electrical Properties of Materials (u). Spring. Credit three hours. Two lectures, one recitation or laboratory.

Description and understanding of physical properties and applications of electrical materials. Electronic structure of atoms, molecules, and crystalline solids. Energy-band concept applied to insulators, semiconductors, and metals. Semiconductors and applications in electronic devices. Thermoelectricity, dielectrics, and magnetic properties.

Graduate Core Program

ITF701 (6601) Topics in Thermodynamics and Kinetics (g). Fall. Credit three hours.

Postulates of thermodynamics and statistical mechanics. Ensembles and distribution functions. Applications of Fermi-Dirac, Bose-Einstein and classical distribution functions. Free energy functions and phase equilibria. Statistical thermodynamics of solutions, surfaces and interfaces, and point defects. Elements of irreversible thermodynamics. Reaction kinetics and diffusion processes in condensed systems. At the level of *Thermodynamics* by E. A. Guggenheim, *Statistical Thermodynamics* by T. Hill, and *Diffusion* by P. G. Shewmon.

ITF702 (6602) Phase Transformations (g). Credit three hours. Spring. Prerequisite: ITF701 or equivalent.

Nucleation theory. Growth theory. Formal theory of nucleation and growth transformations. Spinodal decomposition. Diffusionless transformations. Discussions of topics such as crystal growth from the vapor, solidification, eutectic transformations, solid state precipitation, eutectoid transformations, martensitic transformations with emphasis on the heat treatment of steels, and transformations in polymers and glasses. At the level of *Phase Transformations,* American Society of Metals, 1970.

ITF703 (6603) Elasticity and Physical Properties of Crystals (g). Fall. Credit three hours.

Elastic stress and strain, constitutive relations between stress and strain, elastic wave propagation in crystals, stress fields of dislocations, thermal stresses, stresses at cracks, generalized tensor representation of reversible physical properties of crystals, irreversible thermodynamics, the Onsager relations and transport phenomena in crystals. At the level of *Physical Properties of Crystals* by Nye.

ITF704 (6604) Plastic Flow and Fracture of Materials (g). Spring. Credit three hours. Prerequisite: ITF703 or equivalent.

Introduction to the theory of dislocations. Strain hardening. Dislocation dynamical treatment of yield and flow. Polycrystalline hardening. Interaction of interstitial solute atoms with dislocations. Solution hardening. Two-phase hardening. Time- and temperature-dependent deformation. Dislocation models for cleavage of crystals. Viscosity and visco-elastic behavior. Theories of rubber elasticity. Newtonian and nonlinear viscous flow. Creep and creep rupture. Ductile fracture and the fracture of rubber. Fatigue. At the level of *Elementary Dislocation Theory* by Weertman and Weertman review articles in *Progress in Materials Science,* and various conference reports.

ITF705 (6605) Materials Processing (g). Credit three hours. Spring. Prerequisite: background in materials science.

Discussion of topics in materials processing selected from the following areas: Solidification processes such as casting, welding, and directional solidification; mechanical processing such as rolling, swaging, and drawing; thin film technology; ion implantation; electrochemical processing; diffusional processing; solid state processing, including heat treatment of steels and alloys, precipitation strengthening, and recrystallization. At the level of articles in *Metallurgical Reviews.*

ITF706 (6606) Principles of Diffraction (g). (Same as Applied and Engineering Physics IPB711.) Fall. Credit three hours.

A broad introduction to diffraction phenomena as applied to solid state problems. Production of neutrons and X rays, scattering and adsorption of neutrons, electrons, and X-ray beams. Diffraction from two- and three-dimensional periodic lattices. Crystal symmetry, Fourier representation of scattering centers, and the effect of thermal vibrations on scattering. Phonon information from diffuse x-ray and neutron scattering and Bragg reflections. Standard crystallographic techniques for single crystals and powders. Diffraction from almost-periodic structures, surface layers, gases, and amorphous materials. A survey of dynamical diffraction from perfect and imperfect lattices. Techniques for imaging structural defects. At the level of *Optical Principles of the Diffraction of X Rays* by R. W. James, *X-ray Diffraction* by B. E. Warren, *Electron Diffraction* by Vainshtein, and *Electron Microscopy of Thin Crystals* by Hirsch, et al.

The lecture course will be accompanied by a series of laboratory experiments on fluorescence and polarization of X rays, diffractometer measurements of vibrational amplitudes in crystals, natural widths of emission lines, and identification of crystal structures and crystal orientation by back reflection techniques.

ITF707 (6607) Introductory Solid State Physics (g). (Same as Physics BPS443). Fall.

Credit three hours. Prerequisite: Physics BPS443 or Chemistry BCH793.

A semiquantitative introduction to modern solid state physics, including lattice structure, lattice vibrations, thermal properties, electron theory of metals and semiconductors, magnetic properties, and superconductivity. At the level of *Introduction to Solid State Physics,* 3rd ed., by Kittel.

Other Graduate Courses

ITE553–554 (6553–6554) Project (g). Fall and spring. Credit six hours.

Research on a specific problem in materials or metallurgical engineering.

ITF712 (6612) Selected Topics in Diffraction (g). (Same as Applied and Engineering Phyiscs IPB712.) Spring. Credit three hours.

The Ewald-von Laue dynamical theory applied to x-ray and high-energy electron diffraction in solids. Thermal scattering and measurement of phonon dispersion, frequency spectrum, interatomic force constants, Debye temperatures and vibrational amplitudes. Diffuse scattering, short- and long-range order, precipitation in solids, point defects.

ITF714 (6614) Electron Microscopy (g). Spring. Credit three hours.

Electron optics. Kinematical theory of diffraction with applications to the imaging of stacking faults, dislocations, inclusions, etc. Dynamical theory of diffraction as applied to the calculation of images of various defects. Interpretation and analysis of electron diffraction problems. Application of the stereographic projection to problems in microscopy (e.g., indexing of diffraction patterns from single crystals containing oriented second phases). Applications of dark field microscopy. Instruction in the use of the microscope.

ITF725 (6625) Composite Materials (u,g). (Same as Theoretical and Applied Mechanics IAB680.) Spring. Credit three hours. Staff: faculty from Materials Science and Engineering and Theoretical and Applied Mechanics.

The physical basis of the strength, elastic modulus, and fracture resistance of composite materials; the micro- and macromechanics of composites, their mechanical response, and important composite systems including fabricattion, processing, and design applications. Compatibility and interaction of fibers and matrix. Fatigue, creep, fracture mechanisms. Analysis of primary configurations such as tension and compression members, beams, and plates, including such local effects as bonding, fiber-tip stress concentration, and buckling.

ITG762 (6762) Physics of Solid Surfaces (g). (Same as Applied and Engineering Physics IPB762.) Spring. Credit three hours. Prerequisite: ITF701 and some knowledge of solid state physics.

Equilibrium thermodynamics and statistical mechanics of interfaces. Atomic structure of surfaces in equilibrium. Surface fields, dipoles, and defects in insulators. Electronic and vibrational properties of surfaces. Surface barriers and work functions, surface vibrational and electronic states. Kinetic processes at surfaces. Mass and charge transport. Condensation and evaporation processes. Experimental techniques. Materials drawn from research papers and various review articles in journals such as *Progress in Materials Science, Advances in Chemistry,* and *Solid State Physics.*

ITG763 (6763) Environmental Degradation of Materials (g). Fall. Credit three hours.

Corrosion of industrial alloys in natural environments. Electrochemistry of corrosion in stagnant and convective situations; kinetic models for rate of attack. Passivation and pitting. Stress corrosion and hydrogen brittleness. Environmental attack on glasses and polymers, static fatigue, and crazing. Interactions between nonmetallic surfaces and environmental constituents.

ITG765 (6765) Amorphous and Semicrystalline Materials (g). Spring. Credit three hours.

Topics related to the science of the amorphous state selected from within the following general areas: structure of liquids and polymers; rheology of elastomers and glasses; electrical, thermal, and optical properties of amorphous materials. Presented at the level of *Modern Aspects of the Vitreous State* by Mackenzie, "Glass Transitions" by Shen and Eisenberg in *Progress in Solid State Chemistry,* and *The Physics of Rubberlike Elasticity* by Treloar.

ITG767 (6767) Electrical and Magnetic Properties of Materials (g). Spring. Credit three hours. Prerequisite: Physics BPS454 or equivalent.

Electronic transport properties of metals and semiconductors, semiconductor devices, optical and dielectric properties of insulators and semiconductors, laser materials, dielectric breakdown, structural aspects of superconducting materials, ferromagnetism and magnetic materials. At the level of *Physics of Semiconductor Devices* by Sze, *Ferromagnetism* by Bozworth, and current review articles.

ITG768 (6768) Theory of Crystal Defects (g). Fall. Credit three hours. Prerequisite: ITF701 and ITF703 or equivalent.

The structure and properties of point, line, and planar crystal defects treated from a fundamental point of view. Thermodynamics and kinetics of point defects. Atomistic and continuum theories of dislocations. Thermodynamic treatment of grain boundaries. Structure of grain boundaries. Emphasis given throughout to interactions between the various types of defects and to their roles in important phenomena such as diffusion, precipitation, plasticity, radiation damage. At the level of *Point Defects and Diffusion* by Flynn, *Theory of Dislocations* by Hirth and Lothe, and *High Angle Grain Boundaries* by Gleiter and Chalmers.

ITG769 (6769) Ceramic Materials (g). Fall. Credit three hours. Prerequisite: ITF701 and some familiarity with crystal structures.

Crystal structure and bonding of typical ceramic materials; structure of silicate and nonsilicate glasses; imperfections in oxides: point defects and point defect chemistry, line defects, extended defects; diffusion in stoichiometric and nonstoichiometric ceramics; phase transformations; equilibrium and nonequilibrium phases; grain growth and sintering; plastic deformation and creep; topics from research papers. At the level of *Introduction to Ceramics* by Kingery, *Ionic Crystals, Lattice Defects and Nonstoichiometry* by N. N. Greenwood, and selected research papers.

Mechanical and Aerospace Engineering

The courses in mechanical and aerospace engineering are listed under the following headings: *General, Engineering Design, Mechanical Systems and Analysis, Materials Processing, Transportation, Biomechanics, Aerospace Engineering, Fluid Mechanics, Heat Transfer,* and *Power, Advanced Thermodynamics, and Combustion.*

General

IMG101 (3301) Naval Ship Systems (u). Spring. Credit three hours. Open to freshmen and sophomores only.

An introduction to primary ship systems and their interrelation. Basic principles of ship construction, stability, propulsion, control, internal communications, structure, and other marine systems.

IMG102 (3020) Technology and Society—A Historical Perspective (u). Spring. Credit three hours. Approved as a liberal elective for undergraduates in engineering. Three lecture-discussions. B. J. Conta.

An introduction to the history of technology and its relationship to society. Emphasis will be upon the interactions between technology and the corresponding economic, social, and political developments of the period, rather than upon the internal history of technology. The period of major interest will be the nineteenth and twentieth centuries. Both the material abundance and the explosive problems of the twentieth century had their origins in two dramatic developments of the nineteenth century. One was the emergence of the Watt steam engine as a general purpose prime mover and the vast increase in available power it made possible by the exploitation of the thermal energy of wood and the fossil fuels. A second and less obvious development was a change in the technological motivation. Technology changed from a response to the needs of man (necessity as the mother of invention) to a response to the possibilities of science (invention as the mother of necessity—the technological imperative).

IMG208 The Role of Energy in Society (u,g). Spring. Credit three hours. Prerequisite: permission of instructor.

A seminar-format course including: patterns of energy consumption; U.S. and world comparisons; fuel resources; technology of fuel extraction, energy conversion, and utilization; energy policies and regulations; environmental conflict; limits to growth.

IMG221 (3631) Thermodynamics (u). Either term. Credit three hours. Three recitations. Prerequisite: Mathematics BMA191 and BMA192, Physics BPS112.

The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, multiphase pure substances, gaseous mixtures, and gaseous reactions. Heat-engine and heat-pump cycles. An introduction to statistical thermodynamics.

IMG325 (3325) Mechanical Design and Analysis (u). Either term. Credit four hours. Three recitations, one laboratory. Prerequisite: IAK231.

Application of the principles of mechanics and materials to problems of analysis and design of mechanical systems. Topics considered vary from year to year and range from traditional discipline-oriented work to work cutting across several disciplines. Laboratory considers open-ended design problems. Use of the digital computer for design problems is required.

IMG453 (3053) Mechanical Engineering Laboratory (u). Fall. Credit four hours. One lecture, two laboratories. Prerequisite: IMG325, IMG221, IMF323, and simultaneous registration in IMS326 and IMH324.

Laboratory exercises in instrumentation, techniques, and methods in mechanical engineering. Measurement of pressure, temperature, heat flow, mass transfer, displacement, force stress, strain, vibrations, noise, etc. Use of electronic instruments and fast-response sensors for steady and transient states. Use of density-sensitive optical systems. Error analysis in experimental determinations.

IMG654 (3654) Environmental Control (u,g). Spring. Credit three hours. Prerequisite: courses in thermodynamics, fluid mechanics, and heat transfer. D. G. Shepherd.

Environmental living systems; heating, cooling, and air conditioning. Refrigeration and cryogenic systems and applications. Artificial environments and life-support systems for space and underwater. Production of high vacuum, pressure, temperature, and velocity for simulation of special environments; problems of zero gravity.

IMG656 (3656) Energy and Fluid Systems Laboratory (u,g). Fall. Prerequisite: IMG453 or equivalent.

Individually offered experimental studies. The time allotted, and the number of students accepted for each experiment will be specified by the instructor in each case. Available experiments will range from performance testing of engine components to studies of laser interferometry.

IMG790 (3090) Mechanical Engineering Design Project (g). Either term. Credit three hours each term. Intended for students in the M.Eng. (Mechanical) degree program.

Design of an engineering system or a device of advanced nature. Projects to be carried out by individual students or by small groups with individual assignments culminating in an engineering report by each student. In some cases the project is carried out in collaboration with an external organization, such as an industrial company, research laboratory, or public agency, whose representatives suggest current problems and review the final designs.

IMG791 Mechanical and Aerospace Engineering Research Conference (g). Either term. Credit one hour. For graduate students involved in research projects.

Short presentations on research in progress by students and staff.

IMG799 (7901) Mechanical and Aerospace Engineering Colloquium (g). Credit one hour.

Lectures by Cornell staff members, graduate students, and visiting scientists on topics of interest in aerospace science, especially in connection with new research.

IMG890 Research in Mechanical and Aerospace Engineering (g). Credit arranged. Prerequisite: candidacy for master's degree in mechanical or areospace engineering or approval of the director.

Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the staff.

IMG990 Research in Mechanical and Aerospace Engineering (g). Credit arranged. Prerequisite: candidacy for Ph.D. degree in mechanical or aerospace engineering or approval of the director.

Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the staff.

Engineering Design

IMD464 (3364) Design for Manufacture (u,g). Fall. Credit three hours. Three recitations. Prerequisite: IMM311 or ITB261, or concurrent enrollment in IMM311, or permission of instructor. R. L. Wehe and K. K. Wang.

Design of castings, forgings, stampings, and weldments; unconventional processes. Design for heat treatment, machining, and assembly; selection of materials; dimensioning and fits, jigs and fixtures. Joints, fasteners, and shaft mountings and connections. Specifications for manufacturing and maintenance to minimize fatigue failures and improve reliability; beneficial prestressing; improving the distribution of loads and deflections. Seals and lubrication systems. Components and circuits for fluid power and controls. Short design problems.

IMD663 (3363) Mechanical Components (u,g). Spring. Credit three hours. Three recitations. Prerequisite: IMG325 or equivalent. R. L. Wehe.

Advanced analysis of machine components and structures. Application to the design of new configurations and devices. Selected topics from the following: lubrication theory and bearing design, fluid couplings, torque converters, speed-control devices, shells, thick cylinders, elastic foundation theory, design of pressure vessels, rotating disks, fits, elastic-plastic design, thermal stresses, creep and relaxation, impact, indeterminate and curved beams, plates, contact stresses, gears, and rolling bearings.

IMD672 (3372) Experimental Methods in Machine Design (g). Fall. Credit three hours. One recitation, two laboratories. Prerequisite: IMG325 or equivalent. R. M. Phelan.

Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration and sound measurements, and development techniques as applied to machine design problems.

[IMD674 (3374) Conceptual Design (g). Fall. Credit three hours. Three recitations. Prerequisite: IMG325 or equivalent. Open to undergraduates with permission of instructor. Not offered in 1973–74.

Processes of advanced system or new product evolution as practiced by industry, including product planning, creation of ideas, synthesis into working concepts, and evaluation. A working exposure to engineering components. Numerous projects, much discussion, some lectures.]

IMD680 (3380) Design of Complex Systems (g). Fall. Credit three hours. Two meetings of two hours a week to be arranged. Prerequisite: permission of instructor. R. L. Wehe.

A seminar course relying heavily on student participation in discussing frontier problems such as systems for space and underwater exploitation, salt water conversion, and transportation. Determination of specifications for these systems to meet given needs. Critical discussion of possible solutions based on technical as well as economic and social considerations. Reports which set forth recommendations and the reasoning leading to them will be required.

IMD690 (3390) Special Investigations in Mechanical Design (u,g). Either term. Credit arranged. Prerequisite: permission of director.

Individual work or work in small groups under guidance in the design and development of a machine or in the analysis of experimental investigation of a machine or component.

IMD692 (3392) Special Topics in Engineering Design (u,g). Either term. Credit one hour or more. Ten to fifteen lecture periods a term on a topic of special interest not requiring a course of standard length. Hours to be arranged. Prerequisite: consent of instructor.

Series of lectures by staff members and visiting staff on subjects of current interest. Topics will be announced prior to the beginning of the term. More than one topic may be taken if offered.

Mechanical Systems and Analysis

IMS326 (3326) Systems Dynamics (u). Either term. Credit four hours. Three recitations, one laboratory. Prerequisite: IMG325.

Consideration of the dynamic behavior of systems with emphasis on modeling and analysis techniques and their application. Discipline-oriented topics include analog- and digital-computer simulation; frequency and transient response of linear systems, scalar and vector-matrix models, and dynamic measurement of physical quantities. Laboratories include physical experiments, computer simulations, and design of systems for specified dynamic performance. Applications are drawn chiefly from vibration and control systems.

IMS389 (3333) Computer-Aided Design (u). Spring. Credit three hours. Two lecture-recitations, one computing laboratory. Open to juniors and seniors. Staff.

A broad introduction to computational methods in design. Considerable practical experience in programming large and small digital computers. Interactive computing. Selected applications of numerical methods to problems in mechanical design. Case studies of large programs and problem oriented languages for system simulation, design optimization, computer graphics. Term project.

IMS668 (3368) Mechanical Vibrations (u,g). Spring. Credit three hours. Two recitations, one laboratory. Open to qualified undergraduates. Prerequisite: IMS326 or equivalent.

Further development of vibration phenomena in single-degree and multidegree of freedom linear and nonlinear systems, with emphasis on engineering problems involving analysis and design. Also gyroscopic effects, branched systems, random vibrations, impact and transient phenomena, isolation of shock vibration, and noise and its reduction. Impedance, matrix, and numerical methods. Analog- and digital-computer solutions and laboratory studies.

IMS678 (3378) Automatic Control Systems (u,g). Fall. Credit three hours. Two recitations, one laboratory. Open to qualified undergraduates. Prerequisite: IMS326 or equivalent.

Further development of the theory and implement of feedback control systems with particular emphasis on the application of pseudo-derivative-feedback (PDF) control concepts to linear and nonlinear systems. Analog-computer simulation and laboratory studies of electromechanical, pneumatic, and hydraulic components and systems.

IMS682 (3382) Hydrodynamic Lubrication (g). Spring. Credit three hours. Three recitations. Offered on demand. J. F. Booker.

Designed to acquaint those having a general knowledge of solid and fluid mechanics with the special problems and literature currently of interest in various fields of hydrodynamic lubrication. General topics include equations of viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant films, bearing-system dynamics, and digital and analog computer solutions. Also, selected special topics.

IMS685 (3385) Optimum Design of Mechanical Systems (g). Fall. Credit three hours. Three recitations. D. L. Bartel.

The formulation, as optimization problems, of design problems frequently encountered in mechanical systems. Emphasis is on the choice of the design objective function and the constraints. Finite and infinite dimensional design problems. Theory and application of methods of mathematical programming to the solution of optimum design problems. Examples will be drawn from structures and machine components frequently encountered in mechanical systems.

IMS688 (3388) Computer Simulation and Analysis of Dynamic Systems (g). Spring. Credit three hours. Three recitations. Open to qualified undergraduates by permission of instructor. Some introductory acquaintance with systems dynamics and digital programming areas is assumed. J. F. Booker.

Modeling and representation of physical systems by systems of ordinary differential equations in vector form. Applications from diverse fields. Simulation diagrams. Analog and digital simulation by direct integration. Problem-oriented digital-simulation languages (e.g., CSMP). Digital analysis of stability and response of large linear systems.

IMS690 (3390) Special Investigations in Mechanical Systems (u,g). Either term. Credit arranged. Permission required.

Individual work or work in small groups under guidance in studies in a special field of mechanical systems.

IMS761 (3361) Advanced Mechanical Analysis (g). Fall. Credit three hours. Three recitations.

Advanced topics in mechanical design. Selected topics from design optimization, finite-element methods, design reliability, advanced kinematics, systems analysis, computer-aided design, advanced strength of materials.

IMS771 (3371) Computational Methods of Mechanical Analysis (g). Spring. Offered on demand. Credit three hours. Prerequisite: IMS761 or equivalent. Staff.

Modern computer-based methods for mechanical design analysis as applied to motion analysis of linkages, stress-strain and load-deflection analysis of mechanical structures, pressure-flow analysis of bearing lubricant film systems. Methods include finite elements, transfer matrices, etc.

Materials Processing

IMM311 (3401) Materials and Manufacturing Processes (u). Either term. Credit three hours. Two lectures and one laboratory. This course may be taken in addition to ITB261. Prerequisite: IAK221. K. K. Wang.

Comprehension of material structures. Physical and metallurgical properties of materials, and their control by mechanical and metallurgical means. Conventional and unconventional manufacturing processes. Emphasis is placed on the applications of the knowledge learned in core courses and the correlations among design, material properties, and processing methods.

IMM612 (3451) Analysis of Manufacturing Processes (u,g). Spring. Credit three hours. Three recitations. Prerequisite: IMM311. K. K. Wang.

Analytical treatment of the processes of material removal and plastic deformation, from the interdisciplinary viewpoints of mechanics, thermodynamics, and metallurgy. Emphasis is placed equally on conventional and unconventional processes involving ultrasonic, high-energy beam, electric-discharge, and electrochemical energy sources. Also, economic analysis of production-system and machine-tool dynamics.

[**IMM614 (3475) Introduction to Numerical Control (u,g).** Fall. Credit three hours. Three recitations. K. K. Wang. Not offered in 1973–74.

A broad introduction to numerical control technology, covering both hardware and software aspects. Principles of conventional numerical control systems, adaptive control, and direct computer control of machine tools. Manual and computer-aided part programming methods. Extensive exercises in APT programming. Methodology for economic justification.]

IMM690 (3490) Special Investigations in Materials Processing (u,g). Either term. Credit to be arranged. K. K. Wang.

Independent study of selected topics concerned with analytical or experimental investigation of manufacturing processes. Design, manufacture and test of a machine or a component to be used for materials processing. Topics will include production systems, quality assurance, metrology, or machine tools, in accordance with individual interests. Work will be carried out individually or, for relatively large-scale projects, in small groups.

Transportation

IMT305 (7001) Introduction to Aeronautics (u,g). Fall. Credit three hours. Open to upperclass engineers and others by permission of the instructor. W. R. Sears.

An introduction to atmospheric flight vehicles. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Propulsion systems, including analysis of engine types, propellers, fans, and rotors. Aircraft performance: maximum speed, rate of climb, range and endurance, takeoff and landing; turning performance; maneuver and gust loads; and elements of stability and control.

IMT306 (7002) Introduction to Astronautics (u,g). Spring. Credit three hours. Offered on demand.

Various topics will be treated from the following list: mechanics of trajectories and orbits; propulsion systems, including chemical, nuclear, and advanced; guidance, tracking, and communication systems; the problem of reentry; life support. Applications to be discussed will include missiles, communication and navigation satellites, geology, cislunar probes, lunar and planetary exploration, and deep space probes.

IMT486 (3377) Automotive Engineering (u,g). Spring. Credit three hours. Prerequisite: IMG325. A. I. Krauter.

Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis is on the automobile, particularly with regard to powerplant, driveline, brakes, suspension, and structure. Other vehicle types are considered, including rapid transit and recreational vehicles. Some digital programming experience is assumed. Project.

IMT687 (3387) Dynamics of Vehicles (u,g). Fall. Credit three hours. Prerequisite: IAK221 and IAK231 or equivalents, and permission of instructor. A. I. Krauter.

Intended as an introduction to the dynamics of automobiles and trucks. Emphasis is on the handling behavior of the automobile. Tire theory and suspension analysis. Also, articulated vehicle handling, motorcycle dynamics, and vehicle safety.

Biomechanics

IMB562 (3362) Mechanics of Biological Materials and Systems (u,g). (Same as Veterinary Medicine RLA678). Fall. Credit two hours. One lecture, one laboratory. Intended for students in veterinary medicine and life sciences. Not open to engineering students. Prerequisite: calculus and physics or permission of the instructor. D. L. Bartel.

Basic concepts in engineering mechanics (statics, dynamics, strength of materials). Mechanical properties of biological tissues (bone, soft tissue, muscle). Applications of engineering mechanics to specific biomechanical problems such as fractures, fixation of fractures, strength of suture closure of wounds, analysis of animal motion, mechanical aspects of lameness in horses, and total joint replacement (internal prostheses).

IMB665 (3365) Biomechanical Systems—Analysis and Design (u,g). Spring. Credit three hours. Three recitations. Prerequisite: IAK221, IAK231. D. L. Bartel.

Selected topics from the study of the human body as a mechanical system. Emphasis on the modeling, analysis, and design of biomechanical systems frequently encountered in orthopedic surgery and physical rehabilitation. Investigation of normal and impaired biomechanical systems. Analysis and design of assistive (orthotic) and replacement (prosthetic) devices for impaired biomechanical systems. Analysis and design of man/machine systems used in orthopedic surgery and physical rehabilitation.

IMB690 Special Investigations in Biomechanical Systems (u,g). Either term. Credit arranged. D. L. Bartel.

Independent study of current problems involving the analysis and design of biomechanical systems. In most cases the investigations will involve collaboration with personnel from medical facilities. Work will be carried out individually or, for relatively large-scale projects, in small groups.

Aerospace Engineering

IMA602 (7302) Theoretical Aerodynamics I (g). Fall. Credit three hours. Prerequisite: IMF632–633 or equivalent. Intended for graduate students interested in fluid dynamics or aerodynamics research.

Laplace's equation. Source, sink, and doublet. Vortices. Biot-Savart theorem, the flow field of a vortex. Spherical and cylindrical harmonics. Methods of singularity distributions. Complex-variable methods. Wing theory. Acoustics. Compressible flows, subsonic and supersonic. Shock waves. Hypersonic flow. Rotational flows. Magnetohydrodynamics. Flow in the boundary layer, Prandtl theory. Heat transfer; separation.

IMA603 (7303) Theoretical Aerodynamics II (g). Spring. Credit three hours. Prerequisite: IMF632–633 or equivalent. A. R. Seebass.

Basic equations; fundamental theorems; normal shock waves. Linear and nonlinear small-disturbance equations. Linearized theory of two-dimensional and axisymmetric flows; three-dimensional wings; supersonic area-rule. Exact theories; oblique shock waves and shock wave interactions; method of characteristics; conical flows; hodograph transformation. Improvements in the linearized theory; thickness and Mach number expansions; second-order supersonic flow; sonic boom theory; shock wave interactions. Transonic flow; fundamental equation and similitudes; transonic area-rule; nozzle flows; airfoil design.

IMA611 (7101 and 3667) Physics of Fluids I (g). Fall. Credit three hours. This course may be taken by itself, or may be followed by IMA612.

Fundamental treatment of fluid properties, primarily from a microscopic viewpoint, providing an understanding necessary for advanced study of combustion, air pollution, gas dynamics, and related areas. Kinetic theory of gases: BGK model equation, transport coefficients, mean free path, conservation equations. Chemical kinetics and chemical thermodynamics. Statistical mechanics of non-interacting particles: Fermi-Dirac, Bose-Einstein, and Maxwell-Boltzmann statistics, partition functions, specific heat of gases. Quantum mechanics: atomic structure, rotational and vibrational energy levels. At the level of *Introduction to Physical Gas Dynamics* by Vincenti and Kruger, and *The Dynamics of Real Gases* by Clarke and McChesney.

IMA612 Physics of Fluids II (g). Spring. Credit three hours.

Molecular structure: bonding theory, heats of reaction. Atomic and molecular spectroscopy; applications to pollution. Nonequilibrium statistical mechanics: Boltzmann equation, H-theorem, review of Hilbert-Enskog-Chapman theory, fluctuations, Onsager's relations. Radiative transfer; lasers. At the level of *The Dynamics of Real Gases* by Clarke and McChesney, and *Elementary Statistical Physics* by Kittel.

IMA613 (7102) Gasdynamics (g). Spring. Credit three hours. E. L. Resler, Jr.

Strong shock waves and their use in the production and study of high-temperature gases. High-temperature chemical kinetics and its application to hypersonic external flows, rocket internal flows, and other phenomena of current interest. Chemical relaxation effects of flow fields and the method of characteristics including chemical reactions. Experimental techniques.

IMA621 (7201) Introductory Plasma Physics (g). Fall. Credit three hours.

Intended to be a first course in plasma physics and includes: plasma state, particle orbits in electric and magnetic fields, adiabatic invariants, Coulomb scattering, transport phenomena, plasma oscillations and waves, hydromagnetic equations, energy principle and instabilities, applications to laboratory and space plasmas, introduction to controlled thermonuclear research. At the level of *Elementary Plasma Physics* by Longmire.

IMA622 (7202) Introductory Magnetohydrodynamics (g). Spring. Credit three hours. Offered on demand.

Basic equations of magnetohydrodynamics. Flow problems. Hydromagnetic shock waves. The pinch effect and instabilities. Tensor conductivity and excess electron temperature.

IMA671 (3671) Aerospace Propulsion Systems (u,g). Spring, on demand. Credit three hours. Three recitations. Prerequisite: IMG221, IMF323, or permission of instructor. D. G. Shepherd.

Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion.

IMA704 (7304) Theory of Viscous Flows (g). Spring. Credit three hours. Prerequisite: IMG632 or equivalent. S. F. Shen.

A systematic study of laminar flow phenomena and their methods of analysis. Vorticity diffusion and flow development. Linear and nonlinear exact solutions of the Navier-Stokes equations. Linearized theory: viscous acoustics, the small Reynolds number approximation. Matched asymptotic expansion. The boundary layer equation and its general properties. Singular solution and the separation point. Transformations for compressibility and axisymmetric effects. Similar solutions; approximate methods of calculation. Three-dimensional and unsteady problems. Stability of laminar flows.

IMA705 (7305) Hypersonic Flow Theory (g). On demand. Credit three hours. Prerequisite: IMF632–633 or equivalent. A. R. Seebass.

Hypersonic small disturbance theory and the related similitude; blast wave analogy; entropy layers. Newtonian theory and shock layer structure. Constant density solutions. The blunt body problem; numerical techniques. Viscous and real gas effects; ideal dissociating gas; viscous interactions; other real gas phenomena.

IMA706 (7306) Atmospheric Motions (u,g). On demand. Credit three hours. A. R. Seebass.

One-semester senior or graduate level course, emphasizing a mathematical and physical understanding of synoptic scale motions. The atmosphere; basic scales of synoptic motions; thermodynamics. Equations of motion; rotating and spherical coordinates. Geostrophic flow; the Rossby number; hydrostatic approximation; isobaric coordinates; balanced motions; thermal wind; prognostic equations. Circulation and vorticity; Ertel's theorem and potential vorticity. Planetary boundary layer; Reynolds' stress, Ekman layer. Diagnostic equations; baroclinic motions. Sound, gravity and Rossby waves. Analytical and numerical models; filtered equations; baroclinic model; primitive equations. Cyclogenesis; fronts and frontogenesis. General circulation; energy and momentum; numerical simulation.

IMA707 (7307) Aerodynamic Noise Theory (g). Spring, on demand. Credit three hours. Prerequisite: background in acoustics and fluid dynamics equivalent to IMF339 and IMF632–633 or permission of instructor.

Advanced topics in acoustics relevant to aerodynamic and transportation noise sources and control. Measurements and annoyance scales. Random processes. Geometrical acoustics in inhomogeneous moving media. Kirchhoff and Poisson formulas, diffraction, scattering. Lighthill-Curle formulations for sound generation. Moving sources. Jet, rotor, and boundary layer noise. Absorption and transmission in fluid and at boundaries.

IMA713 (7103) Dynamics of Rarefied Gases (g). Offered on demand. Credit three hours. Prerequisite: IMF632 or equivalent. S. F. Shen.

Flow regimes according to the Knudsen number. Theories of the shock structure at high Mach numbers. Boundary conditions at a solid wall. Slip-flow conditions. Free-molecule flows. Eigen function expansion of the linearized Boltzmann equation. Full-range and half-range moment methods. The model equation approach and recent developments for handling the transition regime.

IMA723 (7203) Intermediate Plasma Physics (g). Spring. Credit three hours. Prerequisite: IEE681 or IMA621 or equivalent.

Collective oscillations in a cold plasma; waves in a warm plasma; application to natural phenomena. Nonlinear theory of collision-free shocks. Quantum effects in solid state plasma waves; plasma-phonon interactions. Introduction to radiation and scattering in plasmas. At the level of *Theory of Plasma Waves* by Stix; and *Radiation Processes in Plasmas* by Bekefi.

IMA792 (7902) Seminar in Aerospace Engineering (g). Credit two hours. Prerequisite: approval of the director.

Study and discussion of topics of current research interest in aerospace engineering. Members of the seminar will prepare and deliver reports on these topics, based on published literature.

IMA793 (7903) Plasma Physics Colloquium (g). Fall and spring. Credit one hour.

Lectures by staff members, graduate students, and visiting scientists on topics of current interest in plasma research.

IMA795 Special Topics in Aerospace Engineering (g). Either term. Credit arranged. Prerequisite: consent of instructor.

Topics of current importance in aerospace engineering and research. Lecture or seminar format. More than one topic may be taken if offered.

IMA890–990 (7801) Research in Aerospace Engineering (g). Prerequisite: admission to the Graduate Field of Aerospace Engineering and/or approval of the director.

Independent research in a field of aerospace science. Such research must be under the guidance of a member of the staff and must be of a scientific character.

Fluid Mechanics

IMF230 (3622) Fluid Mechanics of Gases (u). Fall. Credit three hours. Prerequisite: Mathematics BMA112 or BMA192 and Physics BPS112 or BPS207–208 or equivalent. Not open to Mechanical Engineering students or students planning to major in mechanical engineering. E. L. Resler, Jr.

Use of elementary kinetic theory of gases to derive the Navier-Stokes equations, which are the basis of fluid mechanics. Elementary flow phenomena such as boundary layers, heat flow, shock waves, and incompressible and compressible flow fields will be treated. The applications are not limited to gases. Intended to survey fluid phenomena at an elementary level for those interested in a broad treatment or an introduction to more specialized courses.

IMF323 (3623) Fluid Mechanics (u). Either term. Credit four hours. Four recitations. Prerequisite: IAK231 and IMG221.

Properties of fluids, fluid statics; kinematics of flow, elements of hydrodynamics; dynamics of flow, momentum and energy relations. Euler equations, wave motion; thermodynamics of flow; shocks and gas dynamics; dimensional analysis; real fluid phenomena, laminar and turbulent motion; compressible flow in ducts with area change, friction, and heating; laminar and turbulent layer, lift and drag; supersonic flow.

IMF339 (3639) Acoustics and Noise (u). Fall. Credit three hours. Prerequisite: Mathematics BMA112 or BMA192 and Physics BPS112 or BPS207–208 or equivalent.

Vibration and wave motion. Plane sound waves: transmission and absorption. Spherical waves and sound radiation by surfaces and flow. Loudspeakers. Hearing, noise, and noise control criteria. Architectural acoustics and noise control techniques. At the level of *Fundamentals of Acoustics* by Kinsler and Frey.

IMF632–633 (3632–3633) Fluid Mechanics I and II (u,g). Fall and spring. Credit three hours. Prerequisite: an elementary course in fluid mechanics or permission of instructor.

Stress, deformation, mass, momentum, energy, and constitutive equations. Incompressible potential flow. Viscous flow, boundary layers, convection heat transfer, and separation. Instability and transition. Turbulence and turbulent flows. Body force flows. One-dimensional steady and unsteady flows, including heat addition and friction. External compressible flow. Reacting flows.

IMF636 (3663) Turbomachinery (u,g). Fall. Credit three hours. Three recitations. Prerequisite: IMG221, IMF323, or permission of instructor. D. G. Shepherd.

Aerothermodynamic design of turbomachines in general, followed by consideration of specific types: fans, compressors, and pumps; steam, gas, and hydraulic turbines. Energy transfer between a fluid and a rotor; flow in channels and over blades. Compressible flow, three-dimensional effects, surging and cavitation. Outline design of a high-performance compressor-turbine unit.

IMF690 (3690) Special Investigations in Fluid Dynamics (u). Fall and spring. Credit arranged.

Intended either for informal instruction of a small number of students interested in work to supplement that given in regular courses or for a student wishing to pursue a particular investigation outside of regular courses. Permission of the director is required for registration.

IMF734 (7308) Turbulence and Turbulent Flow (g). Fall, on demand. Credit three hours.

The structure of turbulence and methods of calculating turbulent flows. Topics will include mathematical descriptions of turbulence and experimental measurement techniques; Reynolds stress, eddy viscosity and mixing length; structure of turbulence, including homogeneous isotropic turbulence, correlations and spectra, inertial and dissipation ranges, effects of shear and buoyancy, energy budget; recent developments in turbulent flow calculation methods.

IMF735 (3675) Dynamics of Rotating Fluids (g). Fall, on demand. Credit three hours. Three lectures. Prerequisite: IMF312 and IAA682 or consent of instructor.

Review of classical fluid mechanics. Rotating coordinate systems. Linearized theory for rapidly rotating fluids. Inviscid regions, viscous layers. Large-amplitude steady motions past objects. Unsteady motions. Small amplitude and nonlinear waves in rotating fluids. "Vortex breakdown" in tornadoes and other swirling flows. Theories of vortex breakdown. Boundary layer interactions. Spin-up of fluids in rotating containers. A theoretical course designed for engineers and scientists interested in such applications as fluid motions in rotating containers, geophysical fluid mechanics, energy and mass separation in vortex tubes, etc. Some simple laboratory demonstrations of fundamental phenomena are included.

IMF737 (3677) Numerical Methods in Fluid Flow and Heat Transfer (g). Spring. Credit three hours. Three recitations. Prerequisite: familiarity with the partial differential equations of fluid mechanics and basic Fortran programming. K. E. Torrance.

Finite-difference and finite-element methods are developed for solving multidimensional fluid flow and heat transfer problems. Basic principles are stressed throughout, enabling the methods to be extended to a wide range of physical problems involving convective and diffusive transport. Physical and numerical restraints imposed on transient and steady state numerical solutions are determined. Recent methods are surveyed and compared. Selected examples illustrate applications involving natural convection, flow over objects and within channels, planetary atmospheres and interiors, and flame spread. Assigned problems and the final examination require solution of fluid flow problems on a digital computer.

IMF738 (3685) Nonlinear Wave Propagation (g). Spring, on demand. Credit three hours. Three lectures. Prerequisite: an acquaintance with the Fourier transformation and integration in the complex plane.

Mathematical treatment of nonlinear effects associated with waves in continua. Some particular examples discussed are taken from water waves, gasdynamics, elasticity, plasma physics, and electromagnetic theory. Topics include: Fourier analysis of linear waves; phase and group velocity; dispersion; energy propagation; caustics; kinematic waves; high frequency expansions, diffraction, and ray theory. Nonlinear hyperbolic systems; characteristics; shock waves; energy dissipation; the Burgers equation and its solution. Conservative dispersive systems. The Korteweg-deVries equation and the GGKM method of solution. Nonlinear WKB approximation. Variational principles and Hamiltonian equations for nonlinear dispersive waves. Conservation of wave action. Nonlinear group velocity. Resonant wave interactions and instability of deep water waves.

Heat Transfer

IMH324 (3625) Heat Transfer and Transport Processes (u). Either term. Credit three hours. One lecture, two recitations. Prerequisite: IMG221, IMF323.

Conduction of heat in steady-state, unsteady-state and periodic heat flow; analogic methods; numerical methods; fin surfaces; systems with heat sources. Convection; boundary layer fundamentals; natural convection; forced convection inside tubes and ducts; forced convection over various surfaces. Boiling and condensation. Radiation: emission, absorption, reflection, transmission, and exchanges. Radiation combined with conduction and convection. Heat exchangers; overall heat transfer coefficients; mean-temperature difference; effectiveness; design.

IMH650 (3665) Transport Processes (u,g). Fall. Credit three hours. Three recitations. Prerequisite: basic thermodynamics and fluid mechanics. B. Gebhart.

Description of modes of thermal and mass diffusion and transport. Formulation of the transport equations and their use in engineering and in environmental studies. Conduction and mass diffusion in solid materials. Thermal radiation exchange among assemblies of radiating bodies and as a diffusion process. Nature of nonopaque radiation interaction. Energy and mass diffusion by molecular and turbulent processes in convection. Regimes of transport. Consideration of convection resulting from buoyancy forces and from other forcing conditions in fluids. Various aspects of buoyancy-induced flows emphasized in relation to applications.

IMH651 (3680) Convection Heat Transfer (g). Spring. Credit three hours. Prerequisite: IMH650 or consent of instructor. B. Gebhart.

The diffusion of thermal energy, mass, and momentum is considered. Basic equations are reasoned in detail and applied to problems of current importance in technology and in environmental and ecological studies. Natural convection (buoyancy-induced) flows adjacent to surfaces and in freely rising plumes, buoyant jets, and thermals in extensive media (including stratified) are treated for laminar and for turbulent processes. Transient flows and the conversion of laminar motion to turbulent motion are treated. Thermal instability and the diffusion characteristics in naturally occurring bodies of fluid are studied. Forced flows and resulting convection are also considered; included are effects of property variation and viscous dissipation. Convective flow driven jointly by buoyancy forces and by imposed conditions, such as those in the atmosphere and adjacent to heated surface, is discussed. Limits and mechanisms of these mixed flows are given.

IMH652 (3682) Seminar in Heat Transfer (g). Spring. Credit three hours. Two-hour meetings weekly to be arranged. Prerequisite: permission of professor in charge. B. Gebhart.

Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions.

Power, Advanced Thermodynamics, and Combustion

[IMP304 (3659) The Nature of Thermodynamics (u,g). Fall. Credit three hours. Three recitations. Prerequisite: a course in thermodynamics or permission of instructor. B. J. Conta. Not offered in 1973–74.

History, philosophy, and mathematics of thermodynamics with emphasis on its scope and limitations. The methods of exposition of the concepts and laws of thermodynamics; a comparison of the intuitive, the axiomatic, and the statistical approaches. Principle rather than problem oriented; each student will be expected to develop a special topic in thermodynamics, present it orally, and write a term paper in place of a final examination.]

IMP440 (3640) Thermodynamic Applications (u). Fall. Credit three hours. Prerequisite: IMG221 or equivalent. B. J. Conta.

An introduction to a broad range of engineering applications of thermodynamics to cyclic and noncyclic processes. Heat engine or power cycles, both gas and vapor, steady flow and nonflow. Heat pump or refrigeration cycles, including thermoelectric and absorption refrigeration. Noncyclic energy conversion, with emphasis on combustion engines. The elements of chemical thermodynamics, including the Gibbs availability function and the special case of the Gibbs free energy, will be developed in order to establish the criteria of performance of combustion and other chemical engines. A brief treatment of fuel cells and an introduction to the thermodynamics of biological systems.

IMP441 (3641) Power Systems (u,g). Spring. Credit three hours. Prerequisite: IMG221 and IMF323 or equivalent. F. K. Moore and D. G. Shepherd.

A broad survey of methods of large-scale power generation, emphasizing energy sources, thermodynamic and fluid mechanical cycle considerations, and component description. Power industry, economic, and environmental factors. Long-range trends and projections. Fossil-fueled steam-turbine systems. Exhaust emissions, cooling problems and methods. Peak load problems; gas turbine, energy storage schemes. Topping units, binary cycles, MHD.

IMP442 (3642) Pollution Control in Power and Propulsion (u). Spring. Credit three hours. Three recitations. Prerequisite: IMF323 concurrently, or permission of instructor. Staff.

The major sources of general power and motive power are also sources of air pollution, thermal pollution, and noise. Abatement techniques for these pollutants must be developed if we are to satisfy demands for more power while preserving our environment. An introduction to the major problems associated with each of these types of pollution and to possible methods of control; fundamental technical aspects of the problems and their solutions.

Introduction to the various engineering sciences which form a basis for control technologies.

IMP449 (3660) Combustion Engines (u). Fall. Credit three hours. Three recitations. Prerequisite: IMG221 or IMG221 concurrently.

Introduction to combustion engines with emphasis on application of thermodynamics and fluid dynamics, and on minimization of harmful exhaust emissions. Reciprocating combustion engines, including the stratified charge engine; rotary engines.

[IMP457 Statistical Thermodynamics (u). Spring. Credit three hours. Prerequisite: IMG221. Not offered in 1973–74.

Classical statistics and the statistics of discrete particles from the Maxwell-Boltzmann point of view. Quantum mechanical descriptions of substances and the Gibbs ensemble approach to probabilistic thermodynamics. The evaluation of thermodynamic properties. An introduction to the kinetic theory of gases.]

IMP643 (3652) Combustion Processes (u,g). Spring. Credit three hours. Three recitations. Prerequisite: basic thermodynamics, fluid mechanics, and heat transfer. K. E. Torrance.

An introduction to combustion and flame processes with emphasis on the rate-controlling effects of fluid dynamics, heat and mass transfer, and reaction kinetics. Topics include classification of fuels; heat of combustion and flame temperature; mixture equilibrium; combustion in homogeneous mixtures; deflagrations, detonations, and explosions; ignition, quenching, and burning limits; flame stabilization; turbulent burning; diffusion flames; and burning of droplets and particles.

IMP644 (3691) Processes of Large Scale Heat Rejection (u,g). Fall. Credit three hours. Three recitations. Prerequisite: IMF323 and IMH324 concurrently; or equivalent preparation in fluid mechanics and heat transfer. F. K. Moore and K. E. Torrance.

Application of fluid mechanics and heat transfer to the analysis of problems of large-scale heat rejection. The development of plumes and the effects of heat rejection on temperature cycles of water bodies. Performance and size estimation of cooling towers of evaporative and dry types, including the role of heat exchanger design in such cooling systems for large power plants. The effects of large-scale heat rejection on the planetary boundary layer. Dispersion of thermal effluents in the atmosphere. Urban heat islands and regional warming. Discussion of present and future trends in the development of heat dispersal methods.

IMP648 (3668) Seminar on Combustion (g). Spring. Credit three hours. Meetings three times a week to be arranged. Prerequisite: permission of instructor. F. C. Gouldin, W. J. McLean, and K. E. Torrance.

Discussion of contemporary problems in combustion, such as combustion-generated air pollution, destructive fires, and fuels for future combustion systems. Emphasis will be placed on the experimental and analytical tools required for current combustion research. Topics include numerical techniques, turbulence modeling, temperature and composition measurements, and laser applications.

IMP655 (3672) Energy Conversion (u,g). Spring. Credit three hours. Three lectures. Prerequisite: IMG221 or equivalent.

Primarily an analysis of energy conversion devices as classified into heat engines, chemical engines, and expansion engines. An analysis of each class from the point of view of efficiency and other criteria of performance. A more detailed study of some conventional and direct energy conversion devices including thermoelectric, thermionic, and photovoltaic converters and fuel cells. Energy sources and energy storage, application to terrestrial and space power systems.

IMP690 (3690) Special Investigations in Power, Thermodynamics, or Combustion (u,g). Fall and spring. Credit by arrangement. Intended either for informal instruction of a small number of students interested in work to supplement that given in regular courses or for a student wishing to pursue a particular investigation outside of regular courses. Permission of the director is required for registration.

Nuclear Science and Engineering

See course descriptions for *Applied and Engineering Physics,* p. 68.

Operations Research

See course descriptions for *Industrial Engineering and Operations Research,* p. 108.

Structural Engineering

See course descriptions under *Civil and Environmental Engineering,* p. 77.

Theoretical and Applied Mechanics

Courses in theoretical and applied mechanics are listed under the following headings: *For Undergraduates Only, Engineering Mathematics,* *Mechanics of Solids, Dynamics and Vibrations, Experimental Mechanics, Space Mechanics and Aerospace Structures, Biomechanics,* and *Special Courses.*

For Undergraduates Only

BMA293 (293) Engineering Mathematics (u). Either term. Credit four hours. Prerequisite: BMA192 or BMA194. Lectures, M W F 12:20, 1:25, plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 2, Oct. 30, Dec. 4; Feb. 19, Apr. 2, Apr. 30.

Vectors and matrices, first-order differential equations, infinite series, complex numbers, applications. Problems for programming and running on the automatic computer will be assigned, and students are expected to have a knowledge of computer programming equivalent to that taught in IBE105, Elements of Engineering Communication.

BMA294 (294) Engineering Mathematics (u). Either term. Credit three hours. Prerequisite: BMA293. Lectures, M W 8, 12:20, plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 2, Oct. 30, Dec. 4; Feb. 19, Apr. 2, Apr. 30.

Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, and applications.

BMA295 (293H) Engineering Mathematics (u). Fall. Credit four hours. Prerequisite: BMA192 or BMA194. BMA295 is an honors section of BMA293. Lectures, M W F 12:20, plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 2, Oct. 30, Dec. 4; Feb. 19, Apr. 2, Apr. 30.

Lectures follow the general plan and cover the material of BMA293, with substantially greater emphasis on fundamental unifying concepts. Additional topics may include: an introduction to convergence in metric spaces; the role of complex numbers in clarifying the behavior of real power series and real linear transformations; invariant subspaces of a linear transformation and the Jordan canonical form.

BMA296 (294H) Engineering Mathematics (u). Spring. Credit four hours. Prerequisite: BMA295 or consent of instructor. Honors section of BMA294. Lectures, M W F 12:20, plus recitation periods to be arranged.

Lectures follow the general plan and cover the material of BMA294, with substantially greater emphasis on fundamental unifying concepts. Additional topics may include: a development of the theory of linear ordinary differential equations with constant coefficient via the matrix exponential function; fundamental solution matrices for time-dependent linear ordinary differential equations; particular solutions via the superposition integral. Recitation work will include one major problem-solving project involving modeling, computer programming, and, possibly, experimental verification.

IAK105–106 (1005–1006) Finite Mathematics and Calculus for Biologists (u). (Same as Mathematics BMA105–106.) Fall and spring. Credit four hours a term. Prerequisite: three years of high school mathematics, including trigonometry. Fall: lectures, T Th 11:15, plus two hours to be arranged; spring: lectures, T Th 11:15. Preliminary examinations will be held at 7:30 p.m. on Oct. 4, Nov. 1, Nov. 29; Feb. 14, Mar. 14, Apr. 25. J. C. Dunn; S. A. Levin.

Models, analytic geometry, difference equations, elementary linear algebra, probability, introduction to the calculus, partial derivatives, elementary differential equations, and introduction to interactive computing. Examples from biology will be used throughout.

IAK201 (1001) Introduction to Applied Mechanics (u). Either term. Credit three hours. Two lectures, one recitation per week; four laboratory sessions per term. Prerequisite: registration in Mathematics BMA293. Note: Credit earned for this course, which is an Engineering Core Science, precludes credit in the Field Program in Theoretical and Applied Mechanics for the comparable courses IAK221 (formerly 1021) and IAK231 (formerly 1031).

An integrated treatment of the mechanics of solids and fluids for students in engineering, life sciences, and interdisciplinary programs. Consists of an introduction to the fundamental concepts of statics, dynamics, continuum mechanics, and the properties of materials, with application of these concepts in discussions of several practical examples drawn from solid and fluid mechanics. These include the torsion, bending, and buckling of structural members, time-dependent and statistical problems in elasticity and fluids at rest, perfect fluids, and fluids with friction.

IAK221 (1021) Mechanics of Solids (u). Either term. Credit three hours. Two lectures, one recitation; demonstration laboratory four times per term. Prerequisite: registration in Mathematics BMA293.

Principles of statics, force systems, and equilibrium. Mechanics of deformable solids, stress, strain, statically determinate and indeterminate problems. Analysis of slender bars, shearing force, bending moment, singularity functions. Plane stress, transformation of stress, Mohr's circle of stress and strain. Stress-strain-time-temperature relations, elasticity, plasticity, viscoelasticity. Bending and torsion or slender bars; stresses, deformations, and plastic behavior. Virtual work, energy methods, and applications.

IAK222 (1022) Mechanics of Solids (u). Either term. Credit three hours. Audio-visual, exam-tutorial format. Demonstration laboratory four times per term. Prerequisite: registration in Mathematics BMA293.

Principles of statics, force systems, and equilibrium. Mechanics of deformable solids, stress, strain, statically determinate and indeterminate problems. Analysis of slender bars, shearing force, bending moment, singularity functions. Plane stress, transformation of stress, Mohr's circle of stress and strain. Stress-strain-time-temperature relations, elasticity, plasticity, viscoelasticity. Bending and torsion of slender bars; stresses, deformations, and plastic behavior. Virtual work, energy methods, and applications.

IAK231 (1031) Dynamics (u). Either term. Credit three hours. Two lectures, one recitation; demonstration laboratory four times per term. Prerequisite: registration in Mathematics BMA293.

Principles of Newtonian dynamics of a particle, systems of particles, and a rigid body. Kinematics, frames of reference, motion relative to a moving frame, impulse, momentum, energy. Laws of motion of a system, center of mass, total kinetic energy, moment of momentum, constraints. Rigid body kinematics, angular velocity, moment of momentum and the inertia tensor, Euler equations, the gyroscope. Advanced methods in dynamics. Generalized coordinates, Lagrange's equations, the potential energy function, the kinetic energy function, applications. At the level of *Applied Mechanics-Dynamics* by Housner and Hudson.

Engineering Mathematics

IAA350 (1150) Advanced Engineering Analysis I (u,g). Fall. Credit three hours. Prerequisite: Mathematics BMA294 or equivalent. Lectures T Th 11:15. R. H. Lance.

Methods of applied mathematics as they arise in a systematic study of problems in engineering which give rise to ordinary differential equations. Topics include infinite series, uniform convergence, Bessel's, Legendre, and Gamma function, numerical methods, matrix algebra. initial-value problems, boundary-value problems, and eigenvalue problems in ordinary differential equations. Examination-tutorial course format. At the level of *Mathematics of Physics and Modern Engineering* by Sokolinkoff and Redheffer.

IAA351 (1151) Advanced Engineering Analysis II (u,g). Spring. Credit three hours. Prerequisite: IAA350 or equivalent. R. H. Lance.

A continuation of IAA350, with emphasis on methods of analysis which arise in a systematic study of partial differential equations. Topics include functions of several variables, vector field theory, Fourier series, classical methods for partial differential equations, introduction to numerical methods, classification, and complex variables. Applications to heat flow, stress analysis, and gas dynamics. Examination-tutorial course format.

IAA680 (1180) Methods of Applied Mathematics (g). Fall. Credit three hours. Lectures, M W F 11:15. Open to graduate students or to undergraduates with the consent of the instructor. Intended for students who plan to use applied mathematics frequently; many students will supplement it with IAA681–683. J. A. Burns.

Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; functions of several real variables; vector fields and integral theorems; matrices; partial differential equations. Emphasis on applications and techniques of solution, wherever possible. At the level of *Mathematics of Physics and Modern Engineering* by Sokolnikoff and Redheffer.

IAA681 (1181) Methods of Applied Mathematics II (g). Spring. Credit three hours. Three lectures. Prerequisite: IAA681 or equivalent. J. A. Burns.

Continuation of partial differential equations; Green's function; Fourier and Laplace transforms; complex variables; calculus of variations; tensor analysis.

IAA682 (1182) Methods of Applied Mathematics III (g). Fall. Credit three hours. Lectures, M W 2:30–4. Prerequisite: IAA681 or equivalent. G. S. S. Ludford.

Application of advanced mathematical techniques to engineering problems. Conformal mapping; complex integral calculus; Green's function; integral transforms; asymptotics, including steepest descent and stationary phase; Wiener-Hopf technique; general theory of characteristics; perturbation methods; singular perturbations and boundary layers. Problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, and electromagnetics.

IAA683 (1183) Methods of Applied Mathematics IV (g). Spring. Credit three hours. Three lectures. Prerequisite: IAA682 or equivalent. G.S.S. Ludford.

Topics include: method of matched asymptotic expansions; two timing; WKB approximation; Hilbert-Schmidt and Fredholm theories of integral equations; singular integral equations; Wiener-Hopf equations with application to finite interval; Carleman equation and its generalization; effective approximations; further methods in partial differential equations.

IAA684 (1184) Numerical Methods in Engineering (g). Spring. Credit three hours. Prerequisite: IAA681 or equivalent.

Methods for obtaining numerical solutions to problems arising in engineering. Linear and nonlinear mechanical systems. Ordinary and partial differential equations, initial-value problems, boundary-value problems, eigenvalue problems, and extrema. Calculus of variations. Function-space methods. Applications to vibrations, diffusion, heat transfer, wave propagation, membranes, plates, fluid flow, and celestial mechanics. Simulation of dynamical systems. Analog computation.

IAA770–771 (1170–1171) Foundations of Applied Mathematics (g). Throughout the year. Credit, three hours a term. Two 1¼ hour lectures. Prerequisite: one year of mathematical methods at or beyond the level of IAA350–351, or consent of instructor. J. C. Dunn.

Differs substantially in content and emphasis from methods-oriented courses such as IAA680–681 or Mathematics BMA415–416 or BMA421–423. Presents various applied mathematical topics from the viewpoint of underlying abstract mathematical similarity and provides an introductory treatment of unifying principles from modern analysis and algebra. Subject matter: sets, logic, and switching circuits; algebraic systems and isomorphism; the completion-embedding principle, from natural numbers to distribution theory, including the real-complex embedding, the Riemann-Lebesgue integral embedding, and the function-distribution embedding; the contraction mapping principle, iterative solution techniques, existence-uniqueness theorems, and the Cartesian arithmetization of Euclidean geometry and its extension to Hilbert spaces; the projection principle and approximation theory; symmetric linear operators, matrix diagonalization, and boundary value problems; local approximation of nonlinear functions by linear functions, differentials, variational calculus, gradient methods, generalized Newton-Raphson process, and boundary-value problems. Physical motivation will be drawn from a variety of sources, historical and current, including the literature of theoretical mechanics, communication and control theory, and numerical analysis.

Mechanics of Solids

IAB610 (1210) Introduction to Continuum Mechanics (u,g). Spring. Credit three hours. Three lectures. Minimum registration 15. J. T. Jenkins.

Introduction to the physical aspects of modern continuum mechanics, providing a foundation for further studies in fluid and solid mechanics, materials science, and other branches of engineering. Vectors anud tensors. Analysis of stress and strain. Deformation. Constitutive equations. Balance principles and the derivation of field equations. Examples from fluid dynamics and elasticity.

IAB663 (1263) Applied Elasticity (u,g). Fall. Credit three hours. Lectures, M W 1–2:15. H. D. Conway.

Analysis of thin curved bars. Plane stress and plane strain in the circular cylinder; effects of pressure, rotation and thermal stress. Small- and large-deflection theory of plates, classical and approximate methods. Strain-energy methods. Symmetrically loaded thin cylindrical shell. Torsion of thin-walled members. A first course in the mechanics of elastic deformable bodies with structural applications.

IAB664 (1284) Theory of Elasticity (g). Spring. Credit three hours. Three lectures. H. D. Conway.

General analysis of stress and strain Plane stress and strain. Airy's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Mitchell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space.

IAB680 (1280) Composite Materials (u,g). (Same as Materials Science and Engineering IFT725.) Spring. Credit three hours. Three lectures. Staff: faculty from Materials Science and Engineering and Theoretical and Applied Mechanics.

The physical basis of the strength, elastic modulus, and fracture resistance of composite materials; the micro- and macro-mechanics of composites, their mechanical response, and important composite systems including fabrication, processing, and design applications. Compatibility and interaction of fibers and matrix. Fatigue, creep, fracture mechanisms. Analysis of primary configurations such as tension and compression members, beams, and plates, including such local effects as bonding, fiber-tip stress concentration, and buckling.

IAB765 (1265) Mathematical Theory of Elasticity (g). Spring. Credit three hours. Three lectures.

Development in tensor form of the basic equations of large-deformation elasticity; solution of certain large-deformation problems. Linearization to infinitesimal elasticity. Boussinesq-Papkovich potentials and their application to three-dimensional problems; contact problems; plane stress by method of Muskhelishvili; application of conformal mapping; Cauchy integral techniques in elasticity; torsion problems.

IAB667 (1267) Introduction to The Inelastic Behavior of Solids and Structures (u,g). Fall. Credit three hours.

Introduction to the physical aspects of inelastic material behavior. Microscopic, macroscopic, and idealized models for elastic, plastic, viscous, viscoplastic, and locking materials. Mathematical formulations and methods of solution. Design concepts.

[IAB668 (1268) Theory of Plasticity (u,g). Fall. Credit three hours. Not offered in 1973–74.

Theory of inelastic behavior of materials. Plastic stress-strain laws, yield criteria, and flow laws. Flexure and torsion of bars; thick-walled cylinders; metal forming and extrusion; stress analysis in metals and soils. Limit analysis of beams, plates, and shells. Shake-down. Selected topics in dynamic plasticity.]

IAB771 (1271) Theory of Plates and Shells (u,g). Fall. Credit three hours.

Topics to be covered are: review of classical plate theory; Reissner plate theory; theory of anistropic plates with special emphasis on plates of composite materials and curvilinear coordinates on a surface; general shell theories including Love's first and second approximations and Flügge-Byrne and Naghdi-Reissner shell theories; membrane theory with applications to shells of revolution; Nemenyi-Truesdell stress function; bending theory solutions for cylindrical shells with and without transverse shear deformation.

IAB790 (1290) Continuum Mechanics and Thermodynamics (g). Fall. Credit three hours. Three lectures.

Kinematics. Conservation laws. The entropy inequality. Constitutive equations. Frame indifference. Material symmetry. Simple materials and the position of classical theories in the framework of modern continuum mechanics.

IAB791 (1291) Continuum Mechanics and Thermodynamics of Solids (g). Spring. Credit three hours. Three lectures. Prerequisite: IAB790.

Theory of (nonlinear) elasticity and thermoelasticity: universal solutions, wave propagation, stability theory. Nonlinear viscoelasticity and introduction to more general theories of solids.

[IAB792 (1292) Continuum Mechanics and Thermodynamics of Fluids (g). Spring. Credit three hours. Prerequisite: IAB790. Not offered in 1973–74.

Viscometric flows of non-Newtonian fluids. Theory of mixtures. Oriented media and the theory of liquid crystals.]

Dynamics and Vibrations

IAC662 (1362) Vibration of Elastic Systems (u,g). Fall. Credit four hours. Lectures, T Th S 10:10–11; one laboratory.

Review of vibration of linear-lumped systems, with emphasis on matrix method and transient phenomena. Free and forced vibration of continuous systems, including strings, rods, beams, membranes, and plates. Waves in rods and beams. Orthogonality conditions and application of generalized functions. Rayleigh-Ritz method. Mathieu function and dynamic instability of strings, columns, and other elastic systems. Nonlinear phenomena.

IAC670 (1370) Intermediate Dynamics (u,g). Fall. Credit three hours. Lectures, T Th 1:20–2:35. For graduate students or advanced undergraduate students with consent of instructor. R. H. Rand.

Newtonian mechanics for single particles and systems of particles, conservation laws, central-force motion; rigid-body mechanics, Euler's equations, tops, gyroscopes; generalized coordinates, introduction to Lagrangian mechanics, Hamilton's principle. Text: *Dynamics* by Kane.

IAC675 (1375) Nonlinear Vibrations (g). Spring. Credit three hours. Three lectures. Prerequisite: IAC662 or equivalent.

Phase-plane techniques, singular points, conservative systems, limit cycles. Poincaré-Bendixson theorem, Poincaré's cycles without contact, method of isoclines, Lienard's method, Lyapunov stability, Floquet theory, Hill's and Mathieu's equation, perturbation methods, method of Krylov and Bogoliubov. Applications.

IAC676 (1376) Stability of Motion (g). Spring. Credit three hours. Three lectures.

Physical notions of stability, Lyapunov stability, orbital stability, Lyapunov's second method, validity of linearized variational equations, stability of equilibrium points, stability of periodic motions, Floquet theory, perturbations, structural stability, stability of motions governed by partial differential equations, Poisson stability, ergodicity.

IAC766 (1366) Stress Waves in Solids (g). Spring. Credit three hours. Three lectures.

General equations of elastodynamics. Waves in extended elastic media. Reflection and refraction of waves. Surface waves and waves in layered media. Vibrations and waves in strings, rods, beams, and plates. Dispersion in mechanical waveguides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in anisotropic media and viscoelastic media.

IAC771 (1371) Advanced Dynamics (g). Spring. Credit three hours. Prerequisite: IAC670 or equivalent.

Hamilton's principle, Lagrangian mechanics, principle of least constraint, principle of least action, Gibbs-Appell equations; Hamilton's equations, canonical transformations, Hamilton-Jacobi theory; perturbation theory, von Zeipel method, method of Lie transforms, commensurability effects; quantum mechanics, special relativity. At the level of *A Treatise on Analytical Dynamics* by Pars.

[**IAC781 (1381) Dynamics of Flight (g).** Spring. Credit three hours. Two lectures. Prerequisite: IAA681 and IAC670 or equivalent. Not offered in 1973–74.

Introduction to the dynamics of atmospheric vehicles. Static stability and control. Derivation of the general equations of unsteady motion. Small disturbance equations. Dynamic stability. Dynamic response to controls. Stability augmentation and automatic control. Flight path optimization techniques. At the level of *Dynamics of Flight* by Etkin.]

Experimental Mechanics

IAD659 (1459) Experimental Mechanics (u,g). Fall. Credit three hours. T Th 2:30–4:25.

The student is expected to perform four to six experiments selected to meet his individual interests. Available experiments include: elastic waves in rods, viscoelastic waves and internal damping, linear vibrations of beams and plates, nonlinear response of elastic plates; two- and three-dimensional photoelasticity; plastic response of structures; magnetoelastic buckling of a beam-plate; gyroscopic motion; linear oscillators and analog computers.

IAD660 (1460) Experimental Mechanics (u,g). Spring. Credit three hours.

The student is expected to perform two to three "in-depth" experiments chosen from areas very active in contemporary experimental mechanics and reflecting some of the research interests of the faculty. At present, experiments utilizing holographic interferometry techniques and internal friction techniques are planned. The specific experiments to be performed are selected by the student to meet his individual interests.

Space Mechanics and Aerospace Structures

[**IAG672 (1772) Space Flight Mechanics (u,g).** Fall. Credit three hours. Not offered in 1973–74.

Gravitational potential of the earth; two-body problem; three-body problem; restricted three-body problem; Jacobi's integral; Hill curves; libration points and stability. Lagrange's planetary equations; effect of oblate earth, atmospheric drag, and solar radiation on satellite orbits; satellite attitude control; orbital maneuvers, rendezvous problems.]

IAG673 (1773) Mechanics of the Solar System (u,g). Spring. Credit three hours. Three lectures. Prerequisite: IAC670 or consent of instructor. J. A. Burns.

Application of the principles of mechanics to explain large-scale physical phenomena in the solar system. An understanding of the interplanetary environment will be developed. Topics will include: geophysical principles and ideas as applied to the Earth and other planets; seismic waves, free oscillations, free and forced rotation, gravitational potentials. Equilibrium tidal theory, tidal interactions, orbital evolution of the earth-moon system, spin-orbit coupling of Mercury and Venus. Dynamical characteristics of comets, asteroids, and interplanetary dust. Ralativistic perihelion precession of Mercury.

[**IAG674 (1774) Trajectory Optimization (g).** Spring. Credit three hours. Three lectures. Prerequisite: IAG672 or consent of instructor. Not offered in 1973–74.

Review of calculus of variations. Optimal impulsive trajectories. Maximum principle, bounded controls, singular arcs, and bounded-state variables. Numerical methods, gradient techniques, quasilinearization. Applications to minimum-time and minimum-fuel orbit transfer; rendezvous and interplanetary trajectories.]

Biomechanics

IAH601 (1801) Introduction to Biomechanics, Bioengineering, Bionics, and Robots (u,g). Fall. Credit three hours. Lectures, M W F 1:25. Prerequisite: elementary differential equations, linear algebra, and probability; or consent of instructor. A lecture course intended primarily for undergraduates. An introduction to IAH692, but not necessarily a prerequisite. H. D. Block, R. H. Rand, and staff.

Bionics, the general subject, is the study of possible applications of techniques used by living organisms to the design of engineering devices. Examples are how birds fly, fish swim, and men run; and how animals see, hear, learn, recognize, recall, guess, and reason. The possibility of designing robots to operate in ways analogous to physiological and mental functions will be explored. Typical areas: developments in biomedical engineering, with particular emphasis on the cardiovascular system, mathematical theory of blood flow, artificial intelligence, pattern recognition, neural network and brain models, philosophical questions of computers and the foundations of mathematics, theoretical aspects of competitive and evolutionary ecological systems, and progress in the augmentation of human muscular and mental power. Students interested in particular areas may do individual or team work consisting of study, research, design, or construction.

IAH666 Pattern Classification (u,g). Spring. Credit three hours. Prerequisite: IOA260–270 or equivalent background in probability and statistics. J. C. Dunn.

Graph theoretic and criterion function clustering techniques. Clustering methods based on the theory of fuzzy sets. Linear and nonlinear categorizers. Error correcting procedures. Group averaging techniques and feature extraction. Applications to biological taxonomy, automated character recognition, medical diagnosis.

[IAH692 (1892) Current Research Problems in Bionics and Robots (u,g). Spring. One to four credit hours, as arranged in prior consultation with the staff. Course IAH601 is introductory, but not necessarily a prerequisite. Not offered in 1973–74.

A graduate-level seminar, concentrating on a few of the topics listed under IAH601. Faculty and students will report on current research articles, papers, books, and personal investigations in such areas as: robots designed to learn natural language; artificial intelligence; pattern recognition and scene analysis by machine; adaptive control; and brain and behavior models.]

Special Courses

IAJ704–705 (1904–1905) Seminar in Fluid Mechanics (g). Fall and spring. Credit three hours. Prerequisite: consent of instructor. G. S. S. Ludford.

Study and discussion of topics of current research interest in the field of fluid mechanics. Participants prepare and deliver reports based on pubilshed and unpublished literature.

IAJ821–822 (1921–1922) Project in Mechanics (g). Fall and spring. Credit to be arranged.

A minimum of three credit hours must be completed by each candidate for the Master of Engineering (Engineering Mechanics) degree.

IAJ896 (1996) Research in Theoretical and Applied Mechanics (g). Either term. Credit as arranged.

Thesis, literature survey, or independent research on a subject of theoretical and applied mechanics. Research will be under the guidance of a staff member.

IAJ897 (1997) Selected Topics in Theoretical and Applied Mechanics (g). Either term. Credit as arranged.

Special lectures or seminars on subjects of current interest in the Field of Theoretical and Applied Mechanics. Topics will be announced when the course is offered.

Thermal Engineering

See p. 117.

Courses of Interest to Students from Other Schools and Colleges in the University

Any Cornell student is eligible to enroll in courses offered by the College of Engineering. Certain offerings which have had, or are likely to have a general appeal are listed below. More complete course descriptions may be found under the indicated areas of instruction.

IAH601 (1801) (Theoretical and Applied Mechanics) Introduction to Biomechanics, Bioengineering, Bionics, and Robots (u,g). Fall. Credit three hours. Lectures, M W F 1:25. Prerequisite: elementary differential equations, linear algebra, and probability, or consent of instructor. H. D. Block, R. H. Rand, and staff.

Intended primarily for undergraduates. Bionics, the general subject, is the study of possible applications of techniques used by living organisms to the design of engineering devices.

ICS101 (201) (Computer Science) Survey of Computer Science (u). Fall. Credit three hours. T Th 9:05.

Introduction to the structure and use of the modern computer.

ICS105 (305) (Computer Science) The Computerized Society (u). Fall. Credit three hours. T Th 1:25.

A seminar style course designed to bring the perspectives of the sciences, social sciences, and humanities to the question of the impact of computers on society. Enrollment will be limited to thirty students of varied backgrounds.

ICS211 (202) (Computer Science) Computers and Programming (u). Either term. Credit three hours. Prerequisite: ICS100 or equivalent programming experience. M W 9:05 or T Th 10:10. Laboratory, M T W Th or F 2:30–4:25.

A foundations course in computer programming.

IEE420 (4450) (Electrical Engineering) Bioelectric Systems (u,g). Spring. Credit three or four hours (four hours with laboratory). Prerequisite: Biological Sciences OBC423 or OBC427, or Physics BPS360, or IEE312. Consent of instructor required for laboratory. R. R. Capranica and M. Kim.

Application of electrical systems techniques to biological problems.

IGE101–102 (101–102) (Geological Sciences) Introductory Geological Science (u). Fall:

IGE101. Spring: IGE102. Credit three hours a term. Lectures, T Th 9:05 or 11:15. Laboratory, M T W Th or F 2–4:25, S 10:10–12:35, T 7:30–10 p.m. Field trips. W. B. Travers and staff; J. M. Bird and staff.

Designed to give students a comprehensive understanding of earth processes, features, and history.

IGE103 (111) (Geological Sciences) Earth Science (u). Fall. Credit three hours. (See Earth Science Laboratory IGE105.) Lectures, M W F 9:05. D. E. Karig.

Physical geography, including the spatial relationships of the earth, moon, and sun that determine the figure of the earth, time, seasons, atmospheric and oceanic circulation, and climates.

IGE105 (113) (Geological Sciences) Earth Science Laboratory (u). Fall. Credit one hour. To be taken concurrently with IGE103. Laboratory, W or Th 2–4:25. D. E. Karig.

Observation and calculation of daily, monthly, and seasonal celestial events; topographical mapping and map interpretation; world climatic regions.

IGE131 (203) (Geological Sciences) Geology and the Environment (u). Fall. Credit three hours. Lectures, T Th 9:05. Laboratory, T W or Th 2:00–4:25. A laboratory examination will be held at 7:30 p.m. the last week of the term. Field trips. G. A. Kiersch.

The principles of geological science with emphasis on the physical phenomena and rock properties as they influence the natural environment of man. The cause and effect of geological problems encountered in the planning, construction, and operation of man's works are analyzed in the laboratory, along with the influence of environmental factors.

IGE162 (212) (Geological Sciences) Mineral Resources (u). Spring. Credit three hours. Lectures, M W F 9:05. B. Bonnichsen and W. B. Travers.

Utilization of and man's dependence upon mineral resources; their nature, occurrence, distribution, and availability at home and abroad. Political and economic aspects of their availability and control.

IGE172 (202) (Geological Sciences) Ancient Life (u). Spring. Credit three hours. No prerequisite, but IGE102 is desirable. Lectures, M W F 11:15. J. L. Cisne.

A cultural course devoted to a review of the fossil remains of life in the geologic past as the main basis of the concept of organic evolution. Vertebrate forms from fish to man.

IGE232 (214) (Geological Sciences) Environmental Geology (u). Spring. Credit three hours. Prerequisite: IGE101, IGE103, or IGE131. Lectures, M W 11:15. Laboratory and discussion periods, T W or Th 2–4:25. Field trips. G. A. Kiersch.

The geologic basis of man's environment and its significance in our modern technology. Discussion sections with laboratory problems, field trips, and a term project.

IIB203 (2205) (Civil and Environmental Engineering) Social Implications of Technology (u,g). Fall. Credit three hours. S-U grades optional. Open to all Cornell students beyond the freshman year.

Presents some of the issues pertaining to the development, implementation, and assessment of technology. The social, political, and economic aspects of current problems which have important technological components.

IIE615 (2515) (Civil and Environmental Engineering) Water Resources Problems and Policies (u,g). Fall. Credit three hours. Lecture-discussion. Prerequisite: permission of instructor. Intended primarily for graduate engineering and nonengineering students but open to qualified undergraduates. L. B. Dworsky.

A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water problems, organization, and policies.

IIE633 (2533) (Civil and Environmental Engineering) Environmental Quality (u,g). Fall; spring on demand. Credit three hours. Three lecture-demonstrations. Field trips. Prerequisite: upperclass or graduate student status. C. D. Gates.

An introduction to environmental quality and pollution problems, their nature, causes, and control.

IIE634 (2534) (Civil and Environmental Engineering) Air Quality Control (u,g). Spring. Credit three hours. Three lecture-discussions. Prerequisite: upperclass or graduate student status. C. D. Gates.

An introduction to air quality and air pollution problems.

IIF605 (2605) (Civil and Environmental Engineering) The Law and Environmental Control (u,g). Fall. Credit four hours. Prerequisite: permission of instructor. Designed for seniors and graduate students. P. L. Bereano.

An introduction to the structure and operation of the legal system and an investigation of the manner in which that system may handle environmental problems.

IIF606 (2606) (Civil and Environmental Engineering) Seminar in Technology Assessment (u,g). Spring. Credit three hours. Prerequisite: permission of instructor, based on a showing of adequate background. P. L. Bereano and others.

An interdisciplinary seminar dealing with the social consequences of future technological development and means by which technology can be guided in socially beneficial directions.

IIF611 (2611) (Civil and Environmental Engineering) Economic Analysis of the Private Sector (Microeconomics) (u,g). Fall. Credit four hours. Prerequisite: one year of college-level mathematics. R. E. Schuler.

The economic behavior of individual households and firms; how individual agents combine under different market structures, including competitive markets, monopoly, and monopsony; and the theory of distribution and general equilibrium. Most topics will receive both graphical and mathematical treatment.

IIF612 (2612) (Civil and Environmental Engineering) Economic Analysis of Government (u,g). Spring. Credit four hours. Prerequisite: one year of college-level mathematics and IIF611; or Economics 311. R. E. Schuler.

A continuation of IIF611. (1) The welfare implications of various forms of economic organization and the rationale for government intervention in the microeconomy. The theory underlying investment in government projects and environmental programs. (2) National economic constraints and aggregate behavior (macroeconomics), together with the impact of government activity of these aggregates. Mathematical as well as graphical tools of analysis will be used.

IMG102 (3020) (Mechanical and Aerospace Engineering) Technology and Society—A Historical Perspective (u). Spring. Credit three hours. Three lecture-discussions. B. J. Conta.

An introduction to the history of technology and its relationship to society, especially in the nineteenth and twentieth centuries.

IPC201 (8301) (Applied and Engineering Physics) Nuclear Energy and the Environment (u). Fall. Credit three hours. Two lectures and one two-hour recitation or laboratory per week. The level of presentation assumes knowledge of introductory physics, chemistry, and calculus. T Th 11:15. V. O. Kostroun.

Fundamentals of nuclear radiations; their measurement, interactions, biological and environmental effects, and control.

IPC303 (8303) (Applied and Engineering Physics) Introduction to Nuclear Science and Engineering (u). Spring. Credit three hours. Prerequisite: sophomore physics and mathematics. M W F 8. D. D. Clark.

An introduction to low-energy nuclear physics and nuclear engineering for junior and seniors.

OAE325 (Agricultural Engineering) Introduction to Environmental Pollution (u,g). Spring. Credit three hours. Two lectures, one two-hour discussion every other week. D. C. Ludington.

A general course dealing with the impairment of the environment by the wastes of man.

Cornell University

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